



Systems Engineering Overview

Marshall Space Flight Center
Systems Management Office
Systems Engineering Office

SE Overview Introduction.....	1
FRR Stage Setting I	9
Project Life Cycle Overview	12
Systems Engineering Processes	16
Requirements and	
Verification.....	18
Systems Analysis and Trade	
Studies.....	49
ISS Requirements Issues	
.....	50
Integration and Operations	
.....	90
Safety and Mission Assurance	98
Technical Penetration/Risk Management	104
Reviews	119
Project Organization Roles and Responsibilities	135
White Paper	
Checklist	
FRR Stage Setting II	157
SMO Responsibilities/Personnel	162
Appendices.....	167
Acronym List	168
References.....	175

Course Objectives



Systems Management Office

- To provide an overview of the MSFC project life cycle
- To provide an understanding of what Systems Engineering is and what a Systems Engineer does
- To clarify the roles of the:
 - Project Manager
 - Chief Engineer
 - Project Lead Systems Engineer
- To discuss the available MSFC functional support
- To explore the proven Project Management and Systems Engineering processes that relate to the MSFC philosophy

Covered Material



Systems Management Office

- MSFC project life cycle
- Definitions for Systems Engineering and Systems Engineer
- Key Team Member roles
- The Systems Engineering Processes including:
 - Requirements and Verification
 - Systems Analysis and Trade Studies
 - Integration and Operations

Covered Material



Systems Management Office

- Safety and Mission Assurance
- Project Technical Penetration and Risk Management
- Major Reviews
 - Purpose of the Review
 - Reviewable and/or Ridable Products
 - Participants
 - Outcome
- Project Organization Roles and Responsibilities
- Systems Management Office Roles and Responsibilities

Systems Engineering Definition



Systems Management Office

Systems engineering consists of identification and quantification of system goals, creation of alternative system design concepts, performance of design trades, selection and implementation of the best design, verification that the design is properly built and integrated, and post-implementation assessment of how well the system meets (or met) the goals.

NASA-SP-6105, "NASA Systems Engineering Handbook", pp. 4.

The Domain of Systems Engineering



Systems Management Office

The role of systems *engineering* differs from that of systems *management* in that engineering is an analytical, advisory and planning function, while management is the decision-making function. Very often the distinction is irrelevant, as the same individuals may perform both roles. *Systems* engineering differs from what might be called *design* engineering in that systems engineering deals with the relationships of the thing being designed to its environment and subsystems, rather than with the internal details of how to accomplish its objectives. System engineers must also rely on contributions from the *specialty engineering* disciplines, in addition to the traditional design disciplines, for functional expertise and specialized analytic methods. These specialty engineering areas typically include reliability, maintainability, logistics, test, production, transportation, human factors, quality assurance, and safety engineering.

NASA-SP-6105, "NASA System Engineering Handbook," pp. 6.

The Ideal Systems Engineer



Systems Management Office

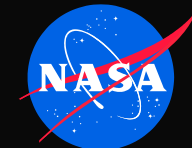
Arthur D. Hall in his classic book, *A Methodology for Systems Engineering*, defines the following traits for an “ideal systems engineer”:

- *An ability to see the big picture*
- *Objectivity*
- *Creativity*
- *Human relations*
- *A broker of information*
- *Education*
- *Experience*

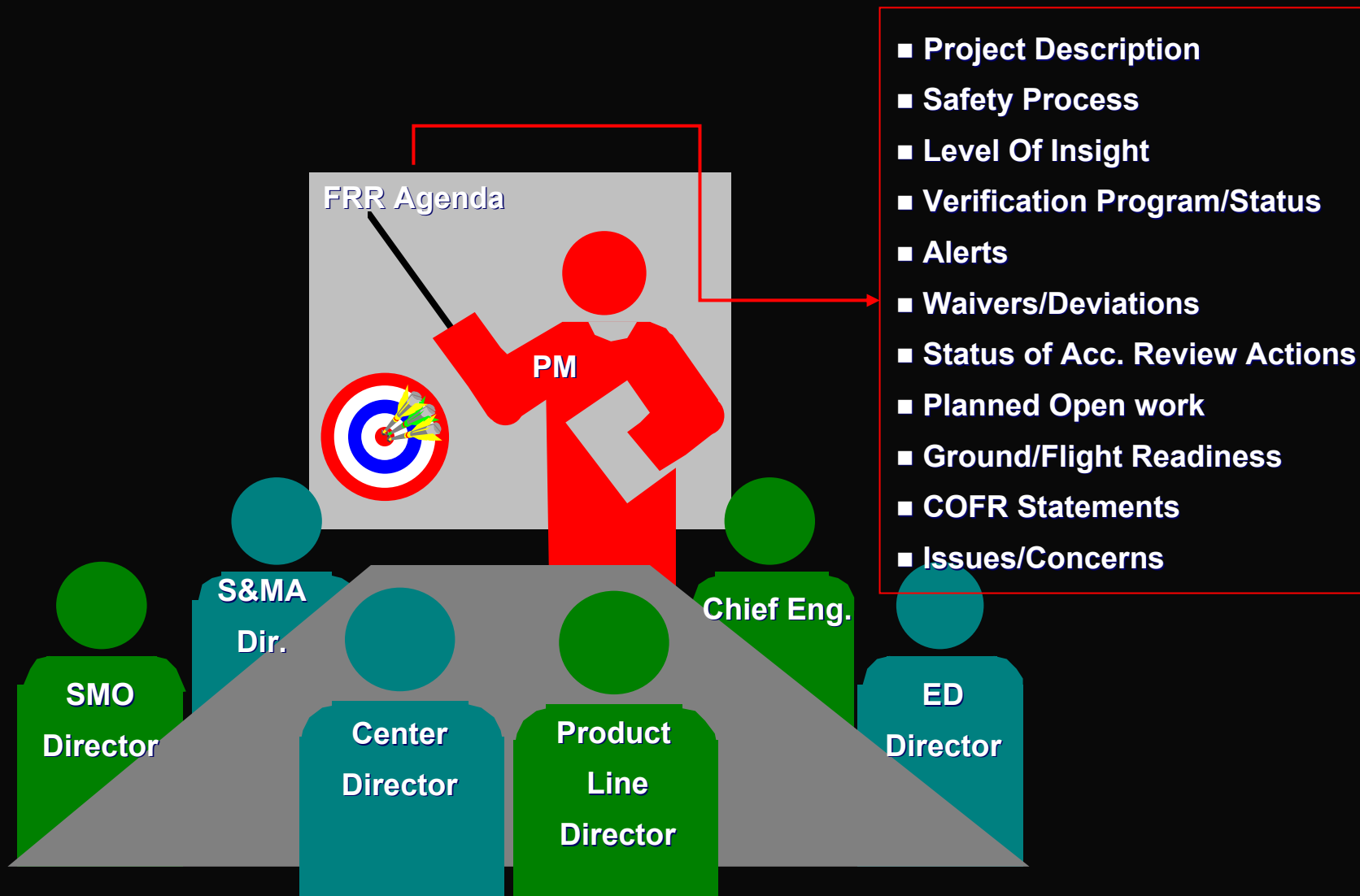


Flight Readiness Review Stage Setting

Flight Readiness Review



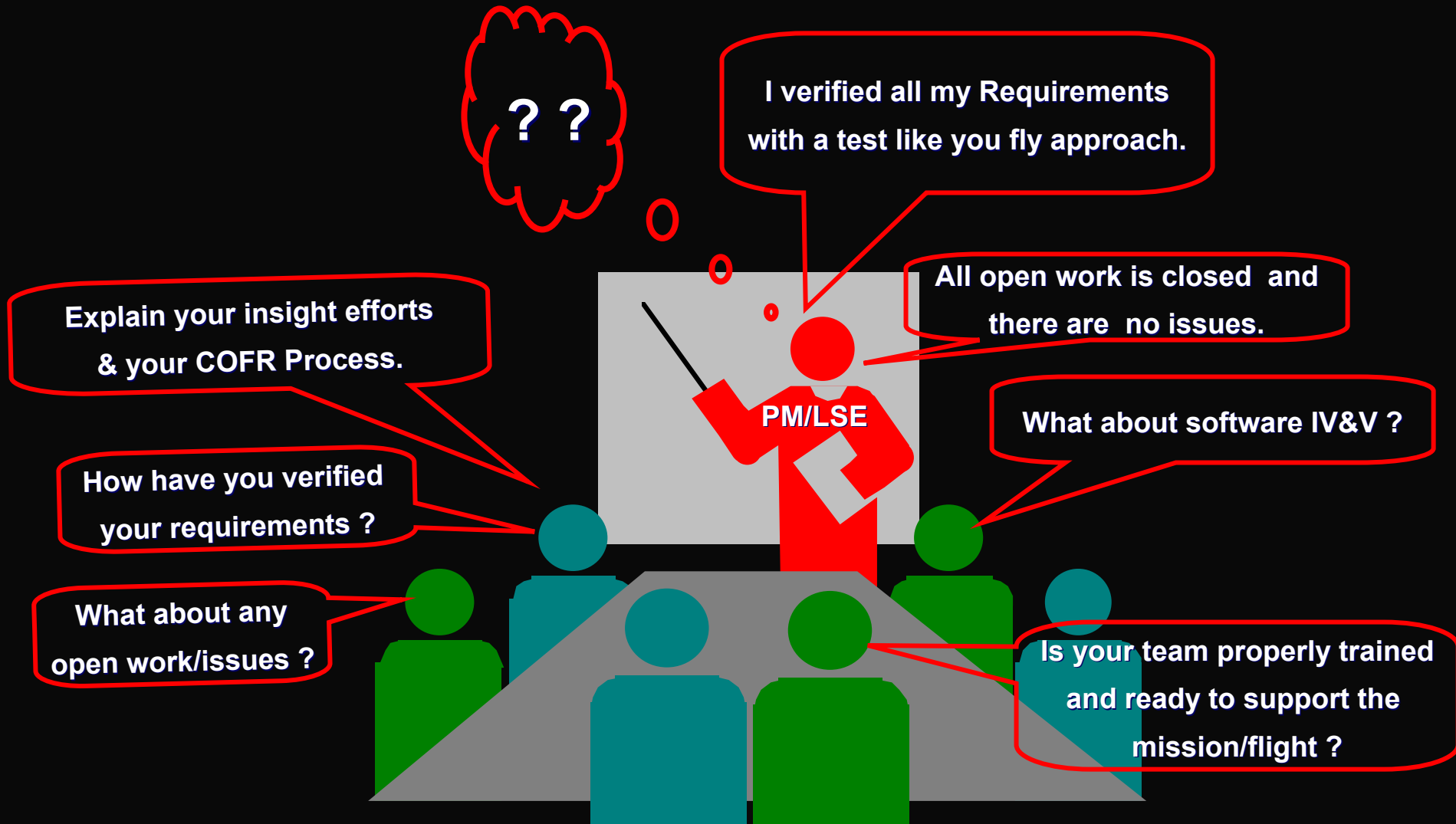
Systems Management Office



Flight Readiness Review



Systems Management Office



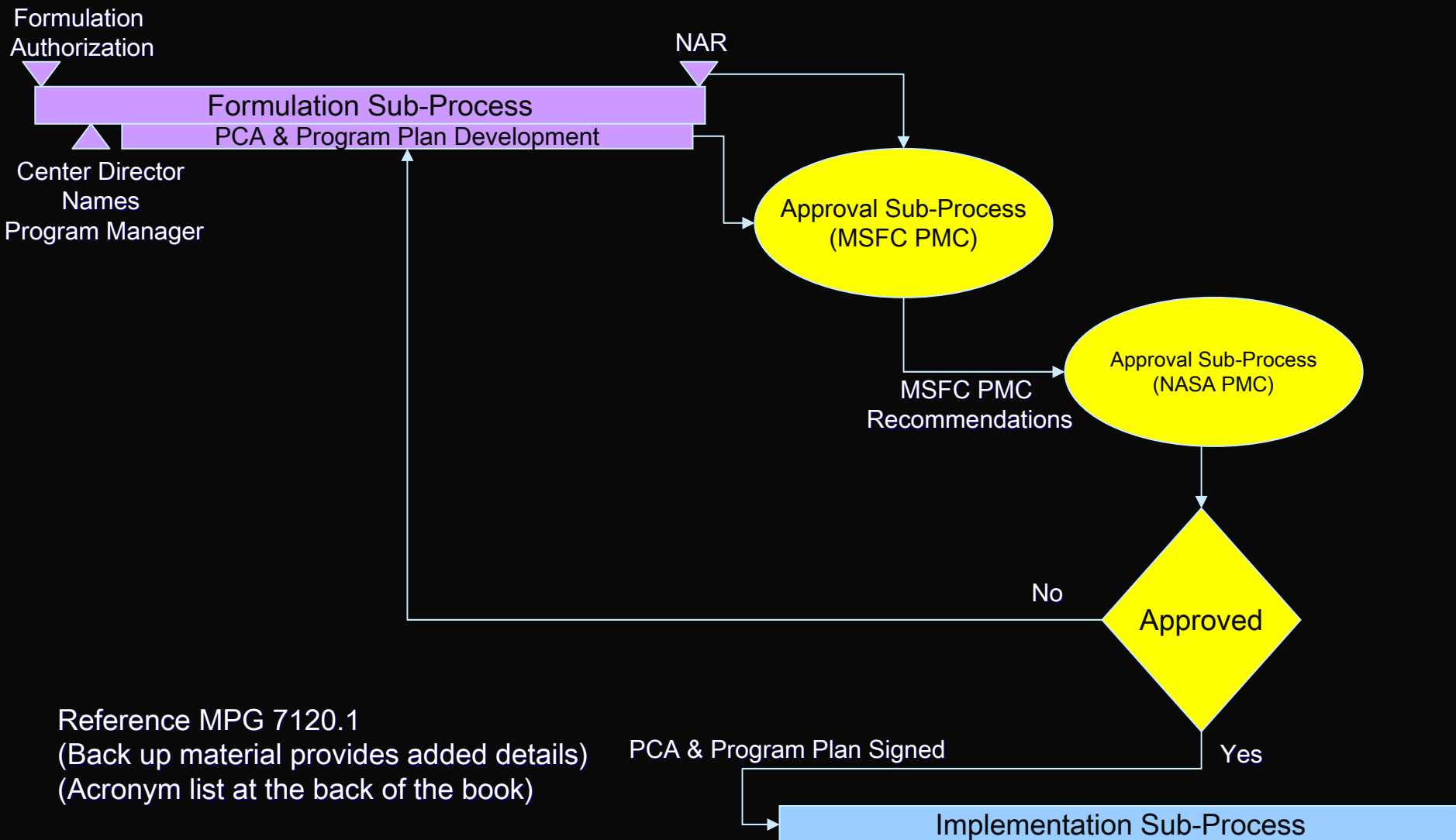


Overview of MSFC Project Life Cycle

MSFC Implemented NPG 7120.5 Top Level Flow (Programs)



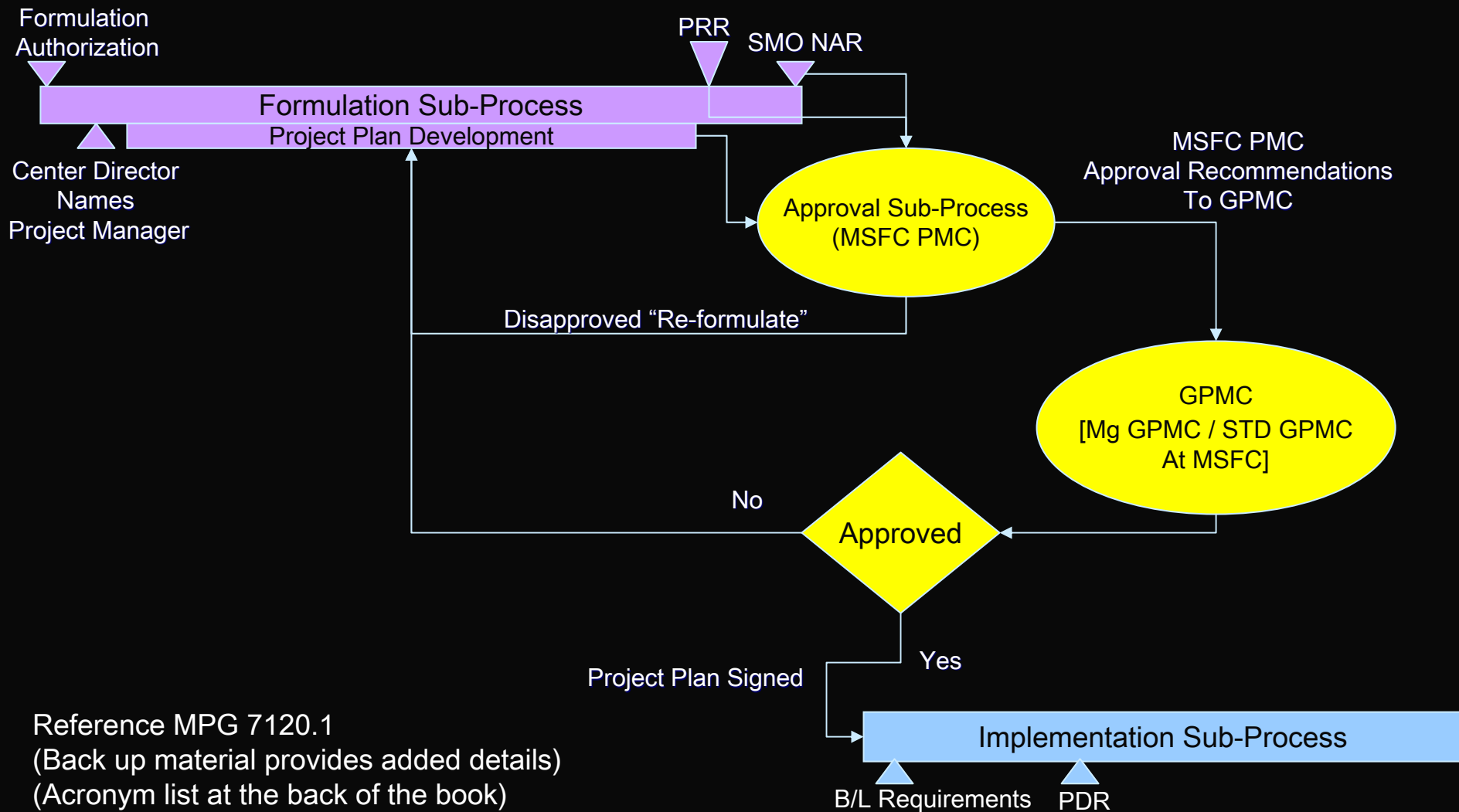
Systems Management Office



MSFC Implemented NPG 7120.5 Top Level Flow (Projects)



Systems Management Office



PMC Process Overview

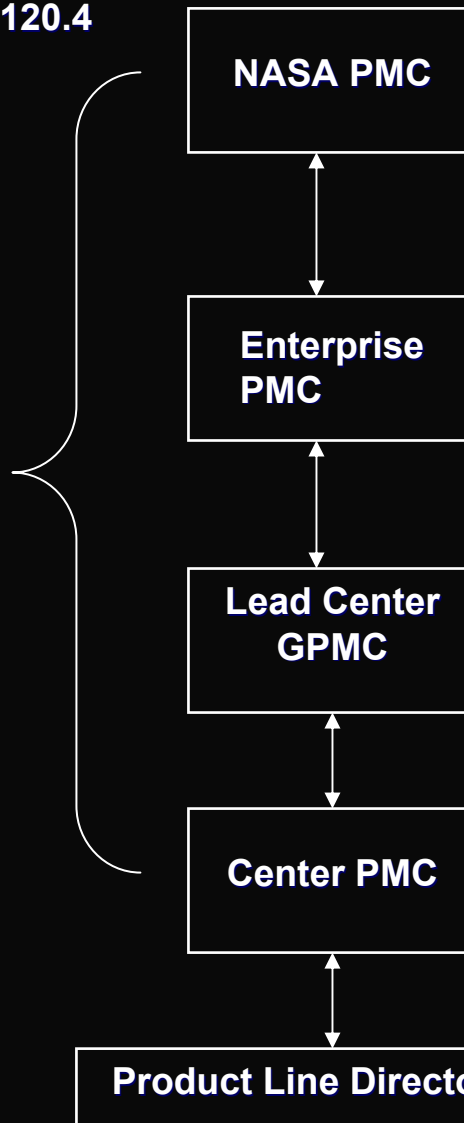


Systems Management Office

PMC Reporting per MPG 7120.4

If Designated as GPMC, the PMC has additional responsibilities:

- ✓ Authorizes Program/Project into next Phase
- ✓ Approves Program/Project Plans
- ✓ Charters and Reviews Independent Evaluations (IA, NAR, IAR)
- ✓ Terminates Program/Project



NASA PMC Unique Authority

- Establishes new Programs
- Terminates Programs
- Designates Center responsible for Program management
- Authorizes direct report Program/Project into next phase
PCA establishes Lead Center GPMC for Program

Enterprise PMC Unique Authority

- Reviews Programs/Projects within Enterprise
- Provides recommendations to Enterprise AA and Agency PMC
- Resolves Enterprise issues with Program/Project

GPMC Unique Authority

- Establishes new Projects (within Program)
- Terminates Projects
- Designates Center responsible for Project management
- Authorizes Projects into next phase

Center PMC Unique Authority

- Commits Center resources
- Reviews Projects that are outside of approved resources or objectives
- Recommends GPMC authorize Projects into next phase
- Recommends GPMC to terminate Projects



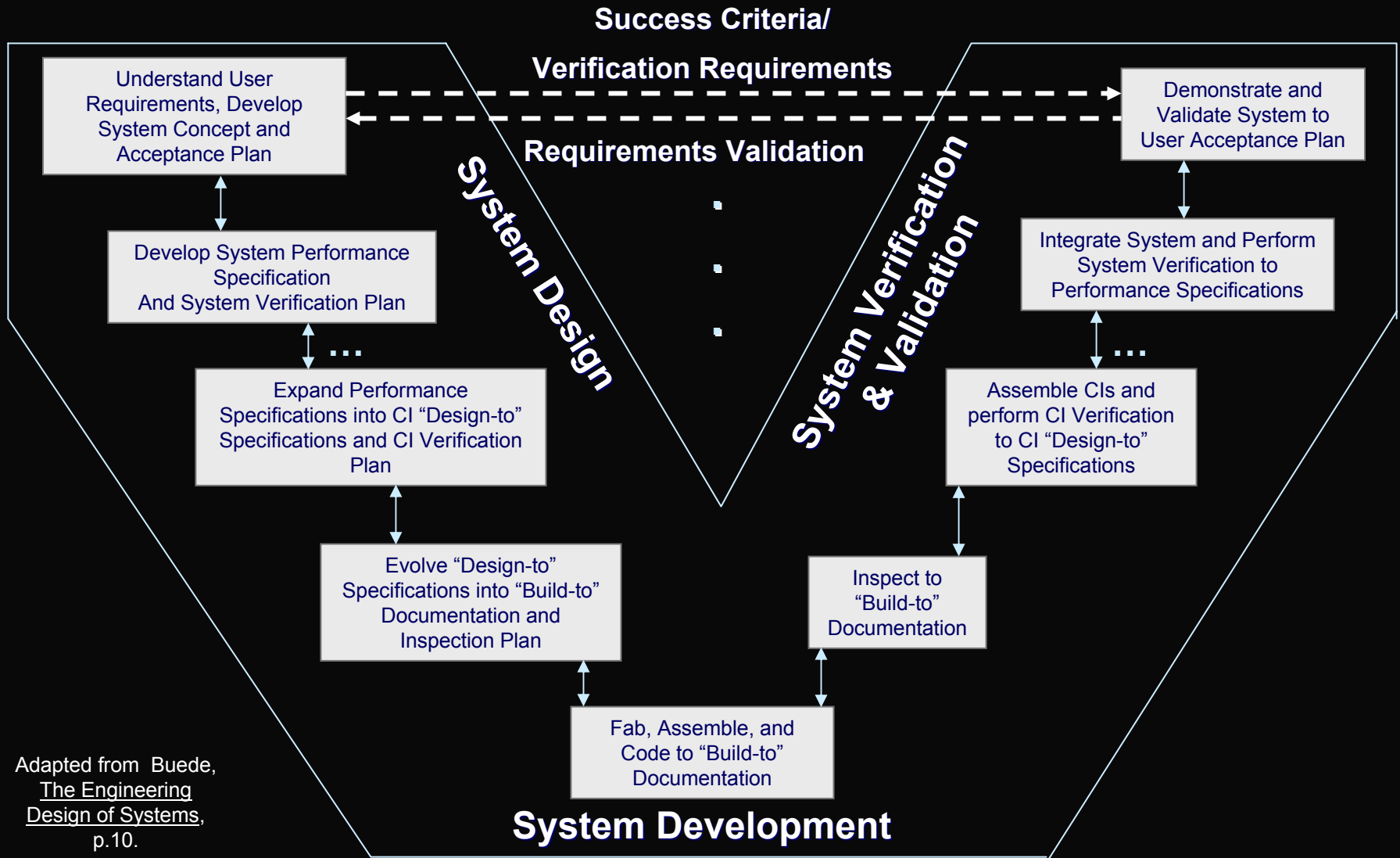
Systems Engineering Processes

In August, 2000, 40% of the MSFC projects surveyed were not utilizing systems engineering processes, mostly due to a lack of training. 44% indicated that the necessary systems engineering tools were unavailable or that they didn't know where to find them. Only 63% had approved project plans; 54% have approved risk management plans; 53% do not practice concurrent engineering, wherein planning for all life-cycle phases is conducted early in the project.

Systems Engineering “Vee”



Systems Management Office



Adapted from Buade,
The Engineering
Design of Systems,
p.10.



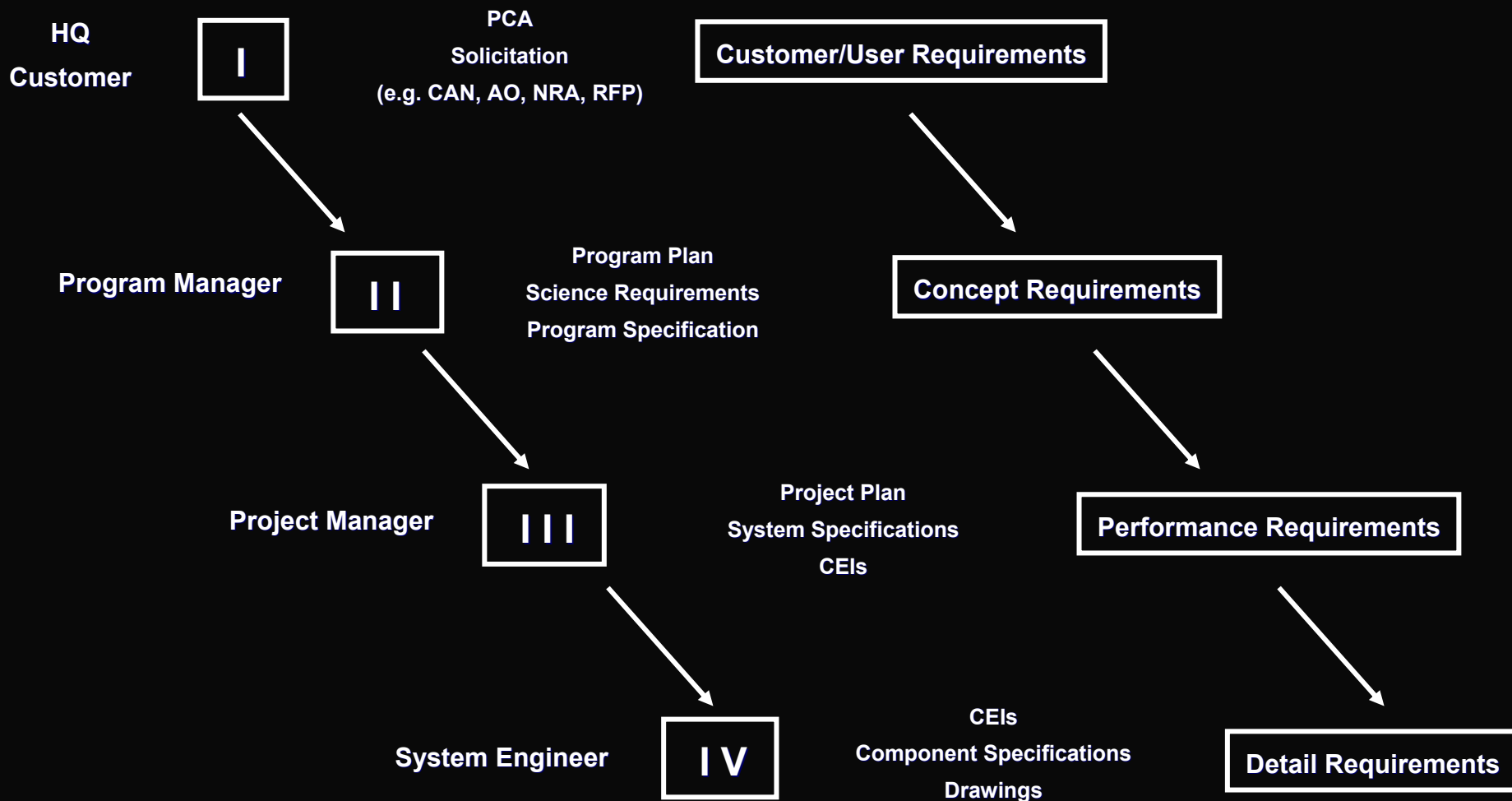
Requirements & Verification

In August, 2000, only 37% of the MSFC projects surveyed had baselined top level requirements. 39% of MSFC projects did not have documented requirements flowdown processes in place, and only 57% felt that they had tools and processes in place to show evidence of compliance. Only 52% have test and evaluation plans derived from verification plans.

Requirements Program



Systems Management Office



Operational Concept



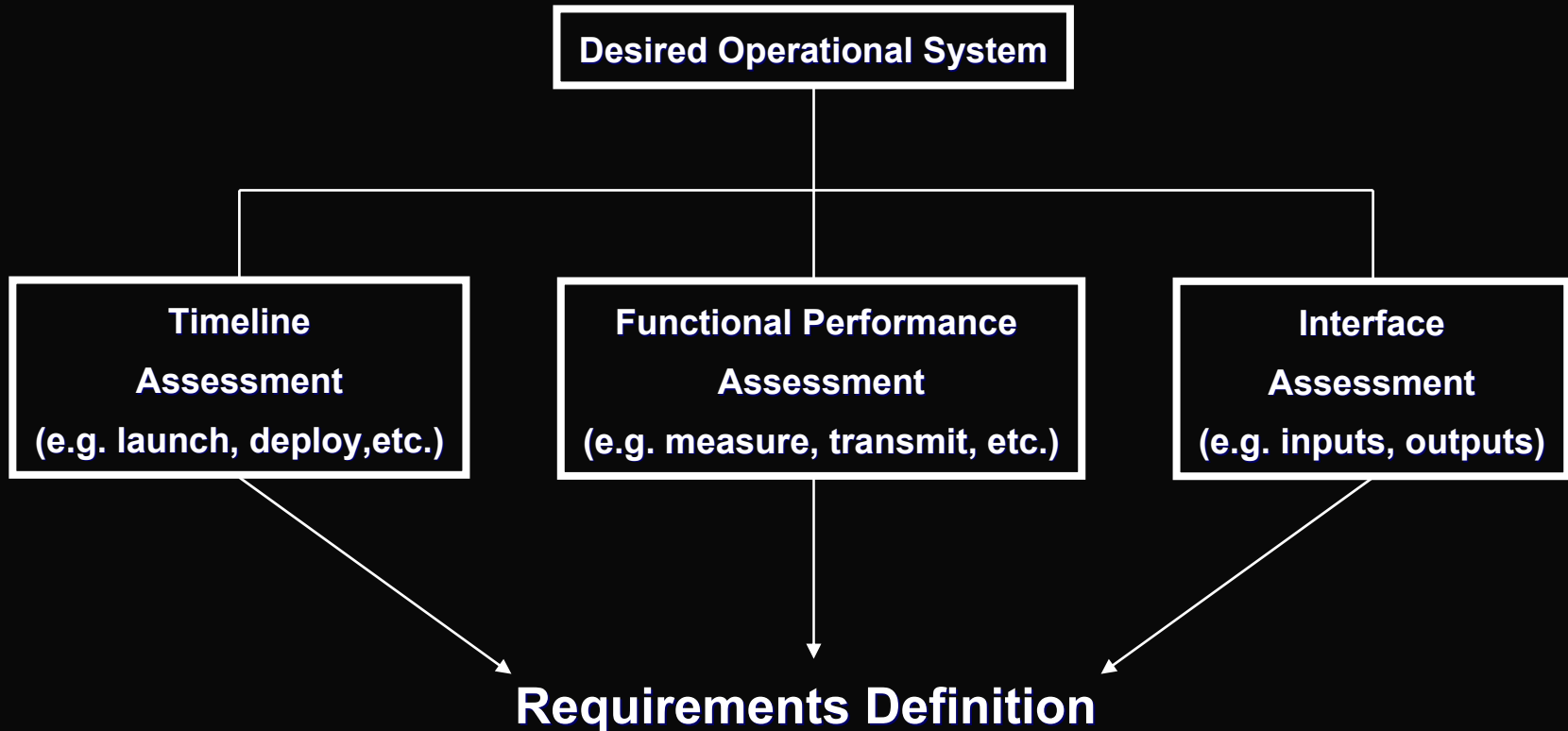
Systems Management Office

- “A Day In The Life” Thought Process
- Covers The Product Life Cycle
 - Integration
 - Launch
 - Deployment
 - Operations
 - Maintenance
 - Disposal
- Inputs From
 - Customers
 - Users
 - Designers
 - Manufacturing
 - Test
 - Flight Operations
 - Ground Operations
 - Launch Vehicle
- Products
 - Introduction of a Specification
 - Concept of Operations Document
 - Functional Decomposition
 - Functional Mission Concepts & Architecture (FMC&A)

Functional Analysis / Decomposition



Systems Management Office



Functional Decomposition Example

Part 1



Systems Management Office

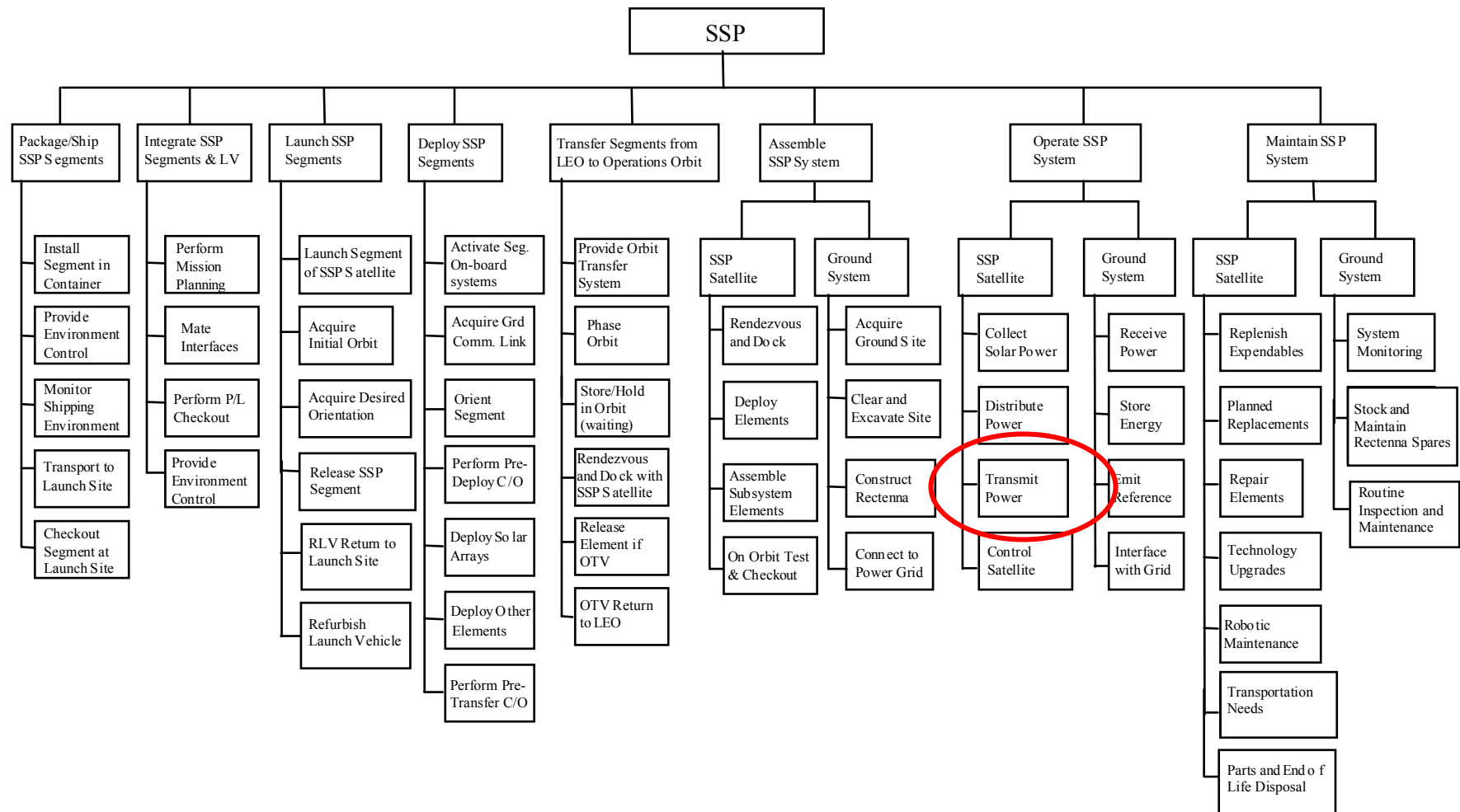


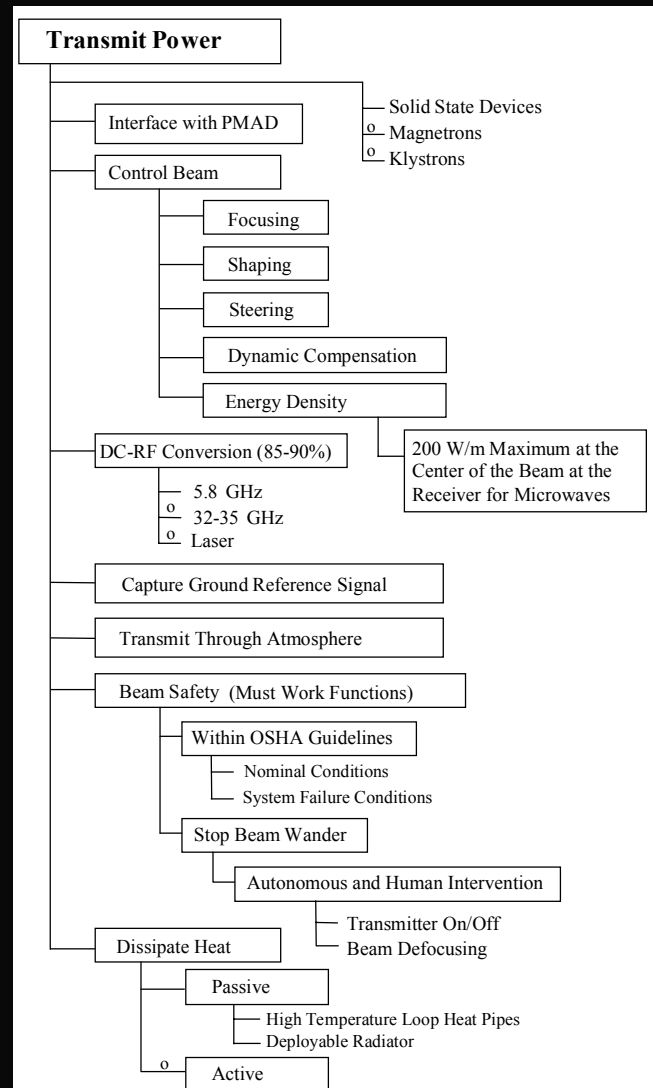
Figure 21. System Level Functional Decomposition

Functional Decomposition Example

Part 2



Systems Management Office



Requirements Lessons Learned



Systems Management Office

- Requirements are the basis for the verification program
- Insure that the stated requirements in a specification are verifiable
 - Non-Verifiable Terms To Look For
 - “.....to the best possible.....”
 - “.....maximum amount.....”
 - “.....as a goal.....”
- The wording of the requirement will have implications on the verification
 - “.....shall operate.....” - functional test
 - “.....shall operate in the environment....” - functional & environmental test
 - “.....shall withstand the.....” - test preferred, analysis an option
 - “The design shall.....” - Verification will be on the “paper” design
 - “The hardware shall.....” - Verification will be on the delivered product

Requirements Lessons Learned



Systems Management Office

- Maintain Requirements Rationale
 - Who made the decision?
 - What assumptions were made?
 - When was the requirement levied?
 - Where did the requirement come from?
 - Why was the requirement needed?
- Requirement Statement vs. Implementation Statement
 - “The launch vehicle shall be able to make the orbital insertion requirement with a single engine out” - requirement
 - “The launch vehicle shall have three main engines” - design solution
- Specification vs. Statement of Work (SOW)
 - “The product shall.....” - Specification
 - “The contractor shall.....” - SOW

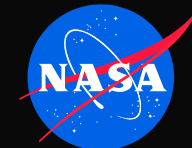
Requirements Lessons Learned



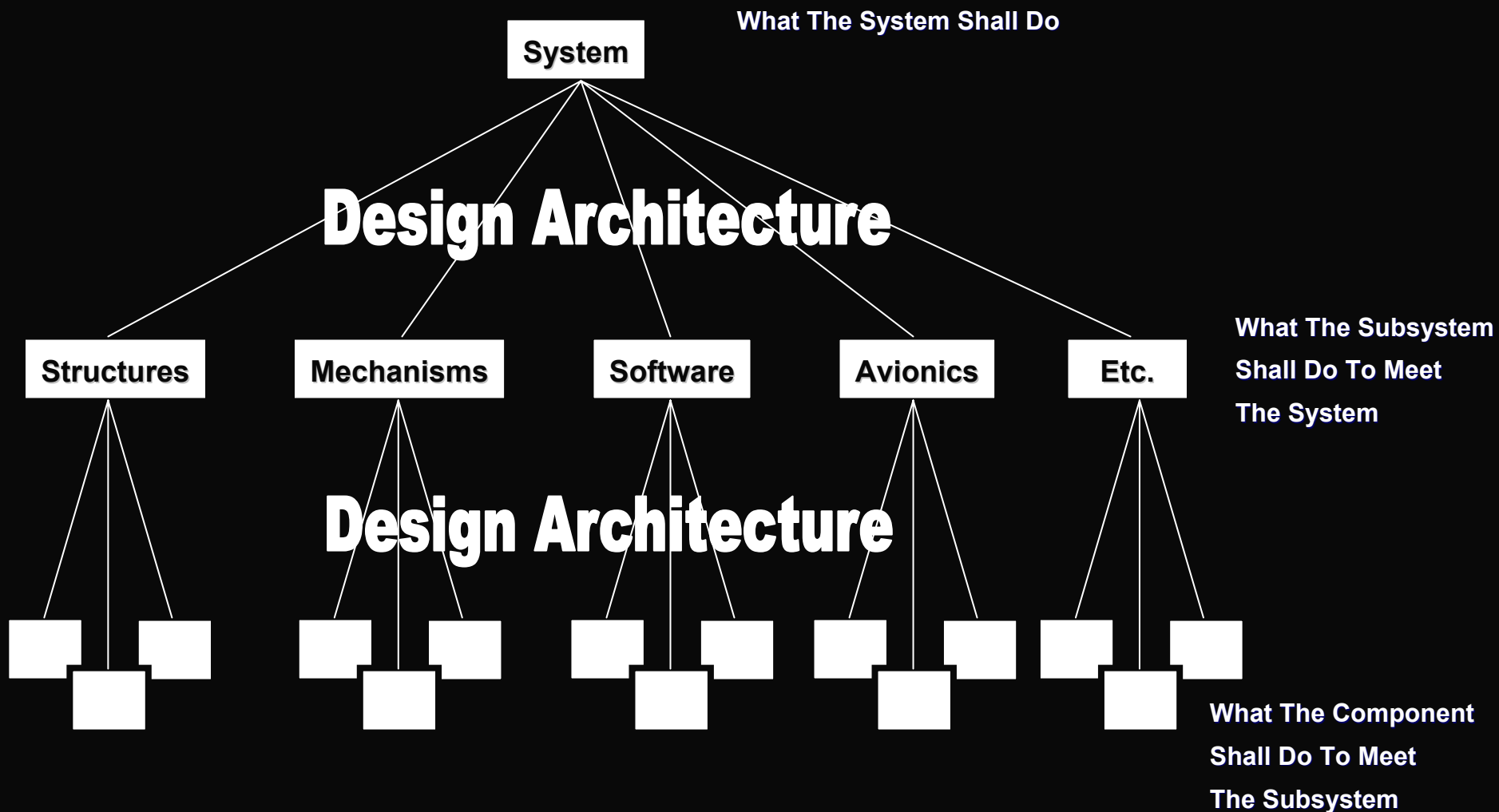
Systems Management Office

- Interface Requirements Document (IRD) vs Interface Control Documents (ICD)
 - IRD ~ Interface Requirements For The Design
 - “...the spacecraft shall supply 28 +/- 5 VDC to the payload....”
 - ICD ~ Controls the Interface Design Solution
 - “....the 28 VDC shall be on connector M1 pin 1 on the spacecraft side and connector F1 pin 1 on the payload side....”
- Pay careful attention, especially with contracted items, to the “shall”, “will”, etc. wording of the requirements - (MIL-STD-961)
- Use the Work Breakdown Structure (WBS) as a means of allocating requirements - (MIL-HDBK-881)

Requirements Allocation



Systems Management Office



Verification Program



Systems Management Office

- Verification Requirements
- Verification Planning
- Verification Success Criteria
- Verification Reports
- Verification Compliance

- Verification - Proof that the product meets the requirements (“Built It Right”)
- Validation - Proof that the product accomplishes its purpose (“Built The Right Thing”)
- MWI 8050.1
 - Verification ~ Confirmation by examination and review of objective evidence that the product meets the design input requirements and is ready for a particular use, function, or mission.

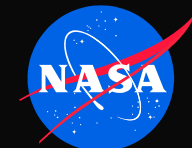
Verification Requirements



Systems Management Office

- Identification of “what” is required to satisfy each of the design input requirements
- The basis of the verification program
- Content
 - Method ~ the method by which the requirement is to be verified (e.g. test, analysis, inspection, similarity)
 - Level ~ the level at which the verification occurs on the product (e.g. system, subsystem, component)
 - Phase ~ the purpose of the verification activity to be performed (e.g. qualification, acceptance)

Verification Requirements Example



Systems Management Office

3.28.4.11 Electromagnetic Compatibility

3.28.4.11.1 Radiated Emissions

SXI equipment shall meet the radiated emission requirements of section 3.2.3.9.3 of the IRD and tested in accordance with MIL-STD-462.

3.28.4.11.2 Radiated Susceptibility

SXI equipment shall meet the radiated susceptibility requirements of Table 3.28-1 and tested in accordance with MIL-STD-462.

Frequency Range	Level
14 kHz - 10 GHz	2 V/m

Table 3.28-1 Radiated Susceptibility Requirements

3.28.4.11.3 Conducted Emissions and Susceptibility

Equipment which have power, telemetry, command, data, and other signals which interface the GOES spacecraft shall meet the conducted emission and conducted susceptibility

VERIFICATION REQUIREMENTS MATRIX

SECTION 3.0	VERIFICATION BY LEVEL AND METHOD						NOTES
PARA. NO.	PHASE						
	D	Q	A	P	F	N/A	
3.18.3			5a				
3.18.4		2bc					
3.18.5			1.1a,4a				
3.18.6		2c,1.2c					
3.19						X	Title
3.19.1						X	Info
3.19.2		2b					
3.19.3			4a				

Verification Planning



Systems Management Office

- Provides an in-depth discussion and visibility into the planned activities for the identified verification requirements
- Provides a detail description of the overall verification approach and organizational structure for implementing the verification program
- Content
 - Overview of the verification approach (e.g. qualification/acceptance, protoflight, spares verification, re-furbish/re-verification, mockup hardware usage)
 - Description of the facilities, GSE, software, etc. necessary to execute the verification activities
 - Time correlated sequence of verification activities
 - Compliance Data review and approval process

Verification Planning Example



Systems Management Office

Opened, the ST will be placed on the handling dolly, and the ST transported to the VATA for further cleanup and processing. Witness samples and contamination deposition monitors will be removed from the chamber for analysis and data will be made available to all Associate Contractors.

4.23 Compatibility Test

The compatibility test will demonstrate satisfactory systems and SI performance under orbital conditions and will also verify satisfactory systems performance under maximum expected flight conditions. The test will be configured to demonstrate systems operation during a simulated launch and expected orbital operations. Orbital operations will be performed through simulated orbits. The test will be performed during thermal vacuum testing and as a part of mission simulation training.

The compatibility test will be controlled from the Payload Control room during thermal vacuum testing and controlled from the Operations Control center, utilizing the command and communication system to the extent possible, during mission simulation testing.

Systems will be in flight configuration except for solar array simulators installed during TV testing, test batteries installed and GSE connected to solar array in place of battery charging. Data transmission and communications with the payload will be operational through use of hat couplers. Systems, including STs will be functionally operated through all configurations, primary and redundant, with cross-strapping. Telemetry formats, data rates, critical systems timing and task recorder recording of engineering and science data and data playback will be verified. The flight software will be installed. Maximum command execution rates will be verified. Systems will be functionally operated with command voltage set at maximum operating voltage, at minimum operating voltage, and normal operating voltage. Maximum power loads are applied at all voltage levels. Trickle charging of batteries during night operations will be verified.

Systems, including SI, will be verified to be without noise while operating in its maximum noise susceptible configuration and as an interacting system is configured to its maximum noise producing configurations. Selected points within the noisy systems will be monitored. EMI voltage levels of selected components will be measured.

Pointing control and aspects determination functions will be demonstrated and verified. Target acquisitions, slews, scan modes, tracking, and fine lock will be verified. The science instruments will operate in low voltage, through operational modes, and provide simulated science data. Safing modes will be verified through ground command, with recovery from each safe mode.

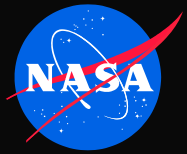
Verification Success Criteria



Systems Management Office

- Provides the detail/specific criteria which determines successful accomplishment for the verification planning activities
- Content
 - Performance Criteria
 - Environmental Test Limits
 - Constraints
 - Inspection Points
 - Effectivity & Location

Verification Success Criteria Example



Systems Management Office

VERIFICATION REQUIREMENTS AND SPECIFICATIONS					EFFECTIVITY			
NUMBER	REQUIREMENT DESCRIPTION	MEAS / STIM	CRITERIA AND SPECIFICATIONS		REMARKS/ CONSTRAINTS	MSFC	KSC	PUEBL O CO
			5. Inside lip of deployer core.					
	Verify Vibration Test Levels		Frequency (Hz)	Test Level	Protoflight Test Levels			
			10-160	0.002 G**2/Hz	(Max Flight +3 dB)			
			160-400	+17.1 dB/Octave				
			400-700	0.36 G**2/Hz	Unit 3 Only			
			700-900	-15.4 dB/Octave				
			900-1300	0.10 G**2/Hz	Test levels applied at			
			1300-1500	+12.4 dB/Octave	Delta II/Longeron Interface			
			1500-2000	0.18 G**2/Hz				
			Three Mutually Perp. Axes					
			Overall Grms = 18.1 +/-10%					
			Duration: 60 Sec/Axis +/-5%					
			Frequency (Hz)	Test Level	Maximum Flight Levels			
			10-160	0.001 G**2/Hz				
			160-400	+17.1 dB/Octave	Unit 1 Only			
			400-700	0.18 G**2/Hz				
			700-900	-15.4 dB/Octave	Test levels applied at			
			900-1300	0.05 G**2/Hz	Delta II/Longeron Interface			
			1300-1500	+12.4 dB/Octave				
			1500-2000	0.09 G**2/Hz				
			Three Mutually Perp. Axes					
			Overall Grms = 12.8 +/-10%					
			Duration: 30 Sec/Axis +/-5%					
1.4	Thermal Vacuum Test					X		
	Verify Thermocouple Locations		Appendix I					

S&MA Safety Assessment & The Verification Program



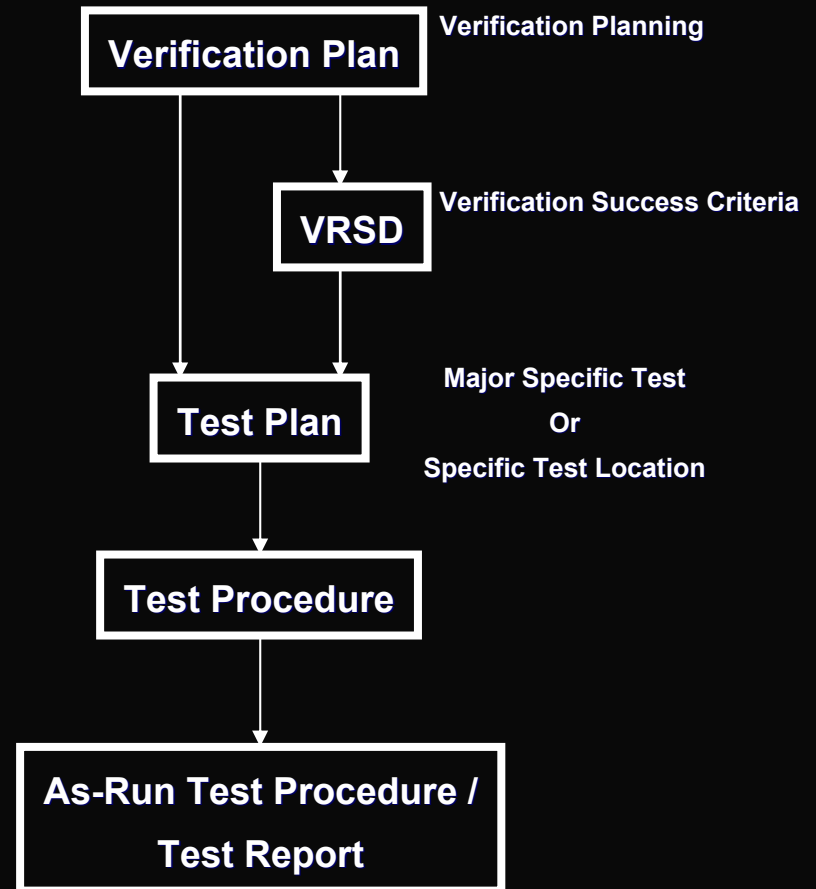
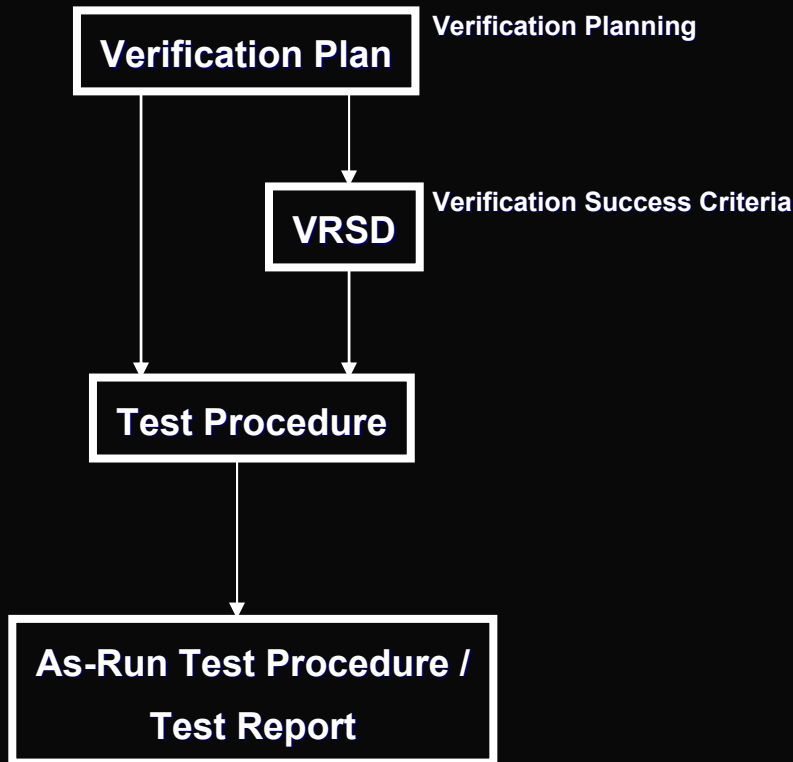
Systems Management Office

- The safety assessment's derived safety verifications (e.g. hazard control verifications) are required to be transmitted into the project's overall verification program per MWI 8050.1 & MWI 1700.2
 - Hazard Reports are not under configuration control
 - Hazard Reports are a particular format for presenting the information to the Safety Panel(s)
 - Any design or verification additions/changes levied on the project need to be controlled and assessed with respect to cost and schedule when added or changed

Verification Plan vs Test Plan



Systems Management Office



Test Readiness Review (TRR)



Systems Management Office

- Purpose - To evaluate the state of readiness to support the performance of a major (i.e. formal verification, acceptance article, etc.) test
- Scope
 - Test Requirements/Objectives
 - Test Procedures
 - Hardware/Software Status
 - Test Facility Status
 - Ground Support Equipment Status
 - Personnel Responsibilities
 - Safety/Hazard Assessment & Controls
- Determined and specified within the Project Plan, System Engineering Management Plan, and Verification Plan

Verification Reports



Systems Management Office

- Records the results of the verification activity
- a.k.a., Compliance Data
- Content
 - Conclusions
 - Recommendations
 - Deviations/Waivers
 - Plots
 - Pictures
 - As Recorded Results
 - Traceability to the Verification Success Criteria

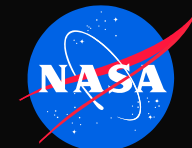
Verification Compliance



Systems Management Office

- Evaluation, Tracking and Statusing of submitted verification reports against the design input requirements
- Content
 - Traceability
 - Verification Report Accountability (i.e. Compliance Data Contact)
 - Non-Conformance Tracking
 - Requirement Status (i.e. open, closed)

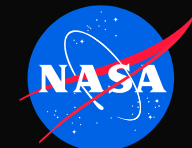
Verification Compliance Examples



Systems Management Office

VERIFICATION REQUIREMENTS COMPLIANCE								
RD/REQ	CEI REQ	VRSD REQ	REQUIREMENT STATEMENT	VER. METH.	COMPLIANCE DATA CONTACT	COMPLIANCE DATA	NON-CONF.	COMMENTS/REMARKS
			45 arc seconds and known to within 10 arc seconds. MSFC shall provide the alignment data to SS/L.					
3.1.1.4.4			HASS to SXI Telescope Alignment MSFC shall be responsible for the alignment between the SXI Telescope and the HASS.					CLOSED
R3.2.6.1			Optical Alignment MSFC shall provide an optical surface that shall permit boresighting the optical axis of the imager to the spacecraft pointing control sun sensor and/or other solar viewing instruments on the solar pointing platform.					CLOSED
	3.16.1		Alignment Reference SXI shall provide an optical alignment reference. SXI shall meet the interface alignment requirements specified in section 3.1.1.4.1 of the IRD.					CLOSED

Verification Compliance Examples



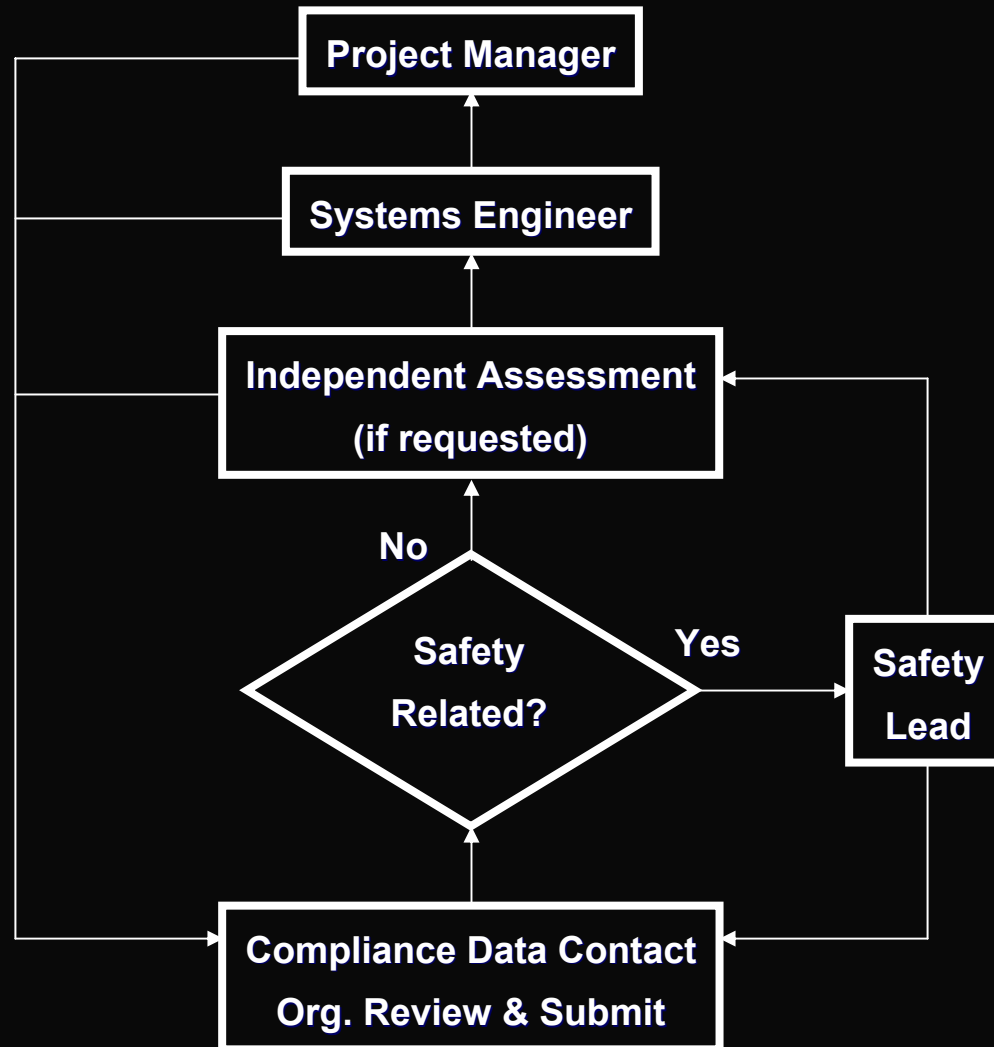
Systems Management Office

VERIFICATION REQUIREMENTS COMPLIANCE								
RD/REQ	CEI REQ	VRSD REQ	REQUIREMENT STATEMENT	VER. METH.	COMPLIANCE DATA CONTACT	COMPLIANCE DATA	NON-CONF.	COMMENTS/REMARKS
		4.5.11	Verify by inspection that the SXI Telescopes alignment reference is reflective and meets the optically flat criteria. (3.1.1.4.1)	4c	P. Johnson R. Peters	JANOS Invoice # 051632		CLOSED
		4.5.13	Verify by inspection the location of the SXI Telescope alignment reference on the front aperture side of the telescope (3.1.1.4.1)	4c	P. Johnson	Memo EB53 (45-97) from EB53/ Kevin Russell to FA67/ Sherry Buschmann		CLOSED
		4.1.5	Verify by inspection that the SXI Telescope alignment reference fits within the SXI Telescope static envelope (3.1.1.4.1)	4c	P. Johnson	NAS Inspection Report for SXI Top Assembly submitted by Deborah Baagdigian (Work Order #96V3154) Test Preparation Sheet EL62-SXI-140		CLOSED
		1.1.7.1	Verify the alignment of the optical axis of the SXI Telescope to the SXI Telescope alignment reference (3.1.1.4.1)	1.1c	R. Hoffman K. Russell	As run SXI Test Procedure (MTCP-FC-SXI-049), run 08/12-13/96 As run SXI Flight Functional Test Procedure (MTCP-FC-SXI-043A), run 05/22-24/97	DEV D-001: changed alignment reference from 45 arc sec. to 2 arc min, 5 arc sec. Waiver D-97-1249	CLOSED

Compliance Data Review Process



Systems Management Office



Verification Lessons Learned



Systems Management Office

- Because the verification program is complete for one mission does not mean it applies to the re-flight mission
 - Must address new or changed requirements
 - Must insure original verification addressed multiple missions
- Verification within IRDs & ICDs
 - Verification Requirements are associated with design requirements and not design solutions
 - Specifications or IRDs - Contain the Verification Requirements
 - ICDs - Information feeds into the Verification Success Criteria
- Perception that Verification is **TEST**, Analysis, Inspection, etc.
- “Test As You Fly/Fly As You Test” methodology

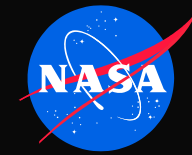
Verification Lessons Learned



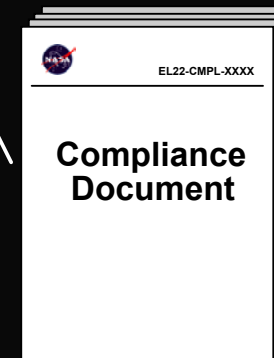
Systems Management Office

- Misuse of the verification method “similarity”
 - Similarity ~ assessing prior data, configuration, processes, and applications and concluding that the item is similar to another item that has been verified to equivalent or more stringent specifications
 - MWI 8050.1 Provides Verification Method Definitions
- The Verification Reports (i.e. Compliance Data) are Records for the project and should be controlled as such per MPG 1440.2 (MSFC Records Management Program)
- Using Risk Management as a tool for determining verification requirements
 - High Likelihood/High Impact/High Risk ~ TEST
 - Low Likelihood/Low Impact/Low Risk ~ TEST or ANALYSIS

Requirements & Verification Database Example



Systems Management Office



REQUIREMENT		
Requirement Number ** 4.1.6.2.5	Requirement Description ** Electromagnetic Compatibility The MSFC hardware shall be electromagnetically compatible with the Orbiter, the PWI Hardware and other USMP-4 payloads per the requirements of MSFC-SPEC-521.	Element ** MSFC Hardware
Multiple Verifications** <input type="checkbox"/>		
TRACEABILITY		
Parent Requirement Source & Number ** JA-2294, Req 4.1		Child Requirement Source & Number **
VERIFICATION		
Verification Method** Test (T)	Verification Location** MSEC	
Verification Description** One set of flight hardware will be tested to ensure electromagnetic compatibility of the hardware in five areas: 1) conducted emissions - emissions generated by ISWE over the power bus lines and signal lines to the Orbiter meets criteria 2) conducted susceptibility - ISWE can operate with the potential emissions that could be generated by the Orbiter over the power bus lines and signal lines 3) radiated emissions - electric field emissions (broadband and narrowband) generated by ISWE do not exceed criteria and do not interfere with the TMU radio (EMI Test continued on Next Page)		
Criteria/Specifications** MSFC-SPEC-521, Test CE01, CE03, TT01, RE02, RE04, RS03, CS01, CS02, CS06		Remarks/Constraints** See Memo EL23 (36-96) from Tony Clark for tailoring of the MSFC-SPEC-521 requirements for ISWE
COMPLIANCE		
Compliance Data Contact(s) Karen Waring Tony Clark		Non Conformances See Compliance Data Test Reports For A Listing Of Anomalous Conditions Found During EMI Developmental Testing
Compliance Data ISWE Dev EMI Test Report dated 3/6/95 Memo EL54(15-95) dated 4/12/95 ISWE Dev EMI Test Report dated 10/12/95 Memo dated 12/12/95 Fax To N. Olson From T. Clark dated 4/15/96 ISWE Dev EMI Test Report dated 4/22/96 Presentation Charts		Comments/Remarks EMI Test Procedure EMI Test Report HR# ISWE-G03
STATUS		
<input checked="" type="checkbox"/> OPEN <input type="checkbox"/> CLOSED <input type="checkbox"/> N/A		
Status Commentary Not Completed Due To ISWE Being Demanifested From Shuttle		

Software Independent Verification & Validation (IV&V)



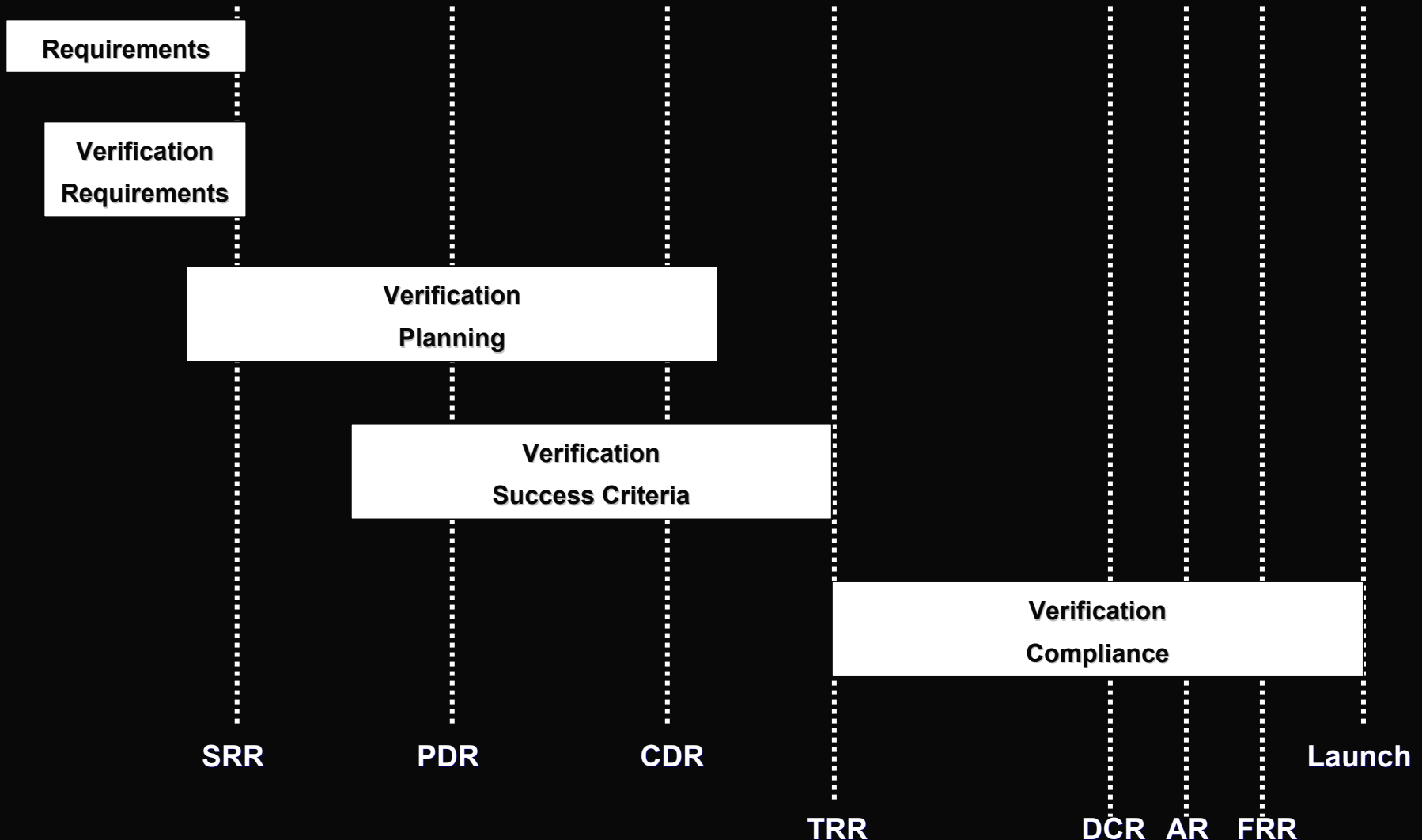
Systems Management Office

- “During the Senior Management Council Meeting on June 24, 1999, Mr. Goldin stated that IV&V for all NASA programs must be conducted at the NASA IV&V Facility.” [Code Q Letter on IV&V, Dated 11/18/99, To EAAs, Center Directors, and Center S&MA Directors]
- “NASA Policy Directive (NPD) 2820.1, "NASA Software Policies" requires that all project plans specify the software assurance process that will be applied early in the formulation phase of the project and implemented throughout its total life cycle.” [Code Q Letter on IV&V, Dated 11/18/99, To EAAs, Center Directors, and Center S&MA Directors]
- New Software IV&V NASA Policy Directive (NPD) is in Draft form
 - Establishes assessment criteria
 - NASA projects containing software shall evaluate themselves against the criteria to determine if a Software IA or an IV&V is required
- MSFC POC - ED14/Tim Crumbley

Requirements & Verification Development vs Project Milestones



Systems Management Office





Systems Analysis & Trade Studies

In August, 2000, only 55% of the MSFC projects surveyed were conducting systems analyses and trade studies that were needed, primarily due to a lack of adequate planning and those were performed as funding and manpower allowed, not as stated priorities. Only 64% maintained technical performance parameters history, including weight and power, and only 58% had technical performance parameters documented and tracked on a basis that would allow trend analysis.

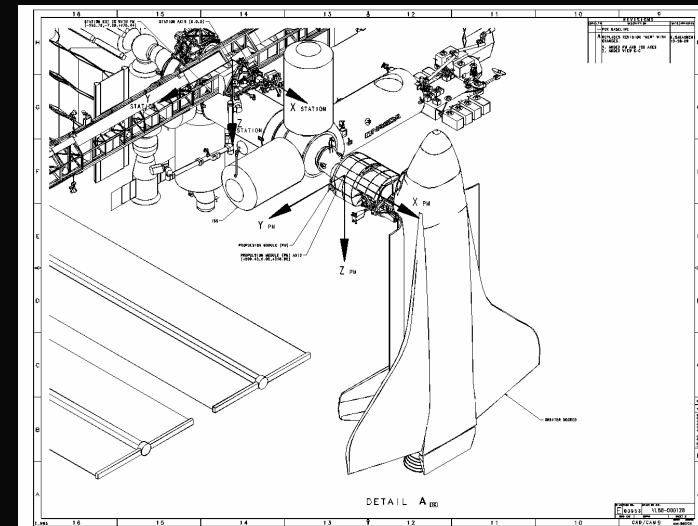
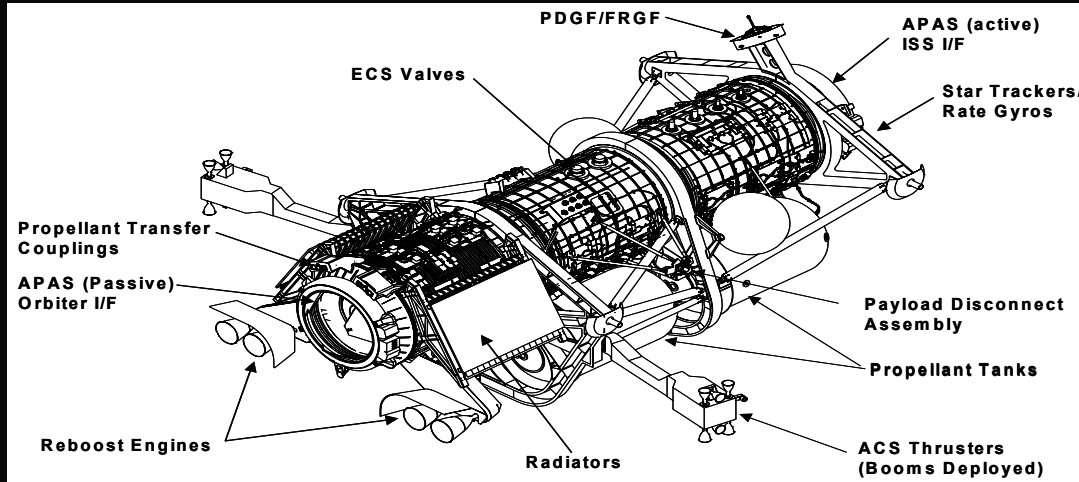


Requirements Issues on the ISS Propulsion Module Project

Requirements Issues on the ISS Propulsion Module



Systems Management Office



Requirements Issues on the ISS Propulsion Module



Systems Management Office

No one came in to the Project after the kickoff and said:

“We want you to add this to what we originally asked you to do...”

So, where did all the requirements growth come from?

Requirements Issues on the ISS Propulsion Module



Systems Management Office

Real issue is requirements instability that evolve from:

- Undefined requirements
 - What does 50% mean – major requirements driver for re-supply operations and system design
 - Not resolved until late in to PDR – Project worked on assumptions agreed to by Program
- Underestimated impacts of known requirements
 - On orbit 12 year life for propulsion system design
 - Propulsion system seals, valves, plumbing
 - Returnability issues
 - Difficult requirement to verify
- Impact of derived requirements on system design
 - 2 Fault Tolerance for safety design requirement
 - Added valves ☑ Added MDMs ☑ Added weight/complexity
- Unfulfilled assumptions about requirements
 - Heritage Shuttle hardware proposed as cost savings in original proposal
 - Thermal vacuum and acoustic testing not included in Boeing proposal – ISS policy of using analytical solution contributed to difficulty in resolution
- Growth
 - Tunnel size increased from 32 to 45 inches
 - Larger tunnel ☑ thicker MMOD shielding ☑ Greater weight
- Reallocation of requirements
 - Helium Re-supply concept of operations shifted He pallet from Shuttle to PM

Requirements Issues on the ISS Propulsion Module



Systems Management Office

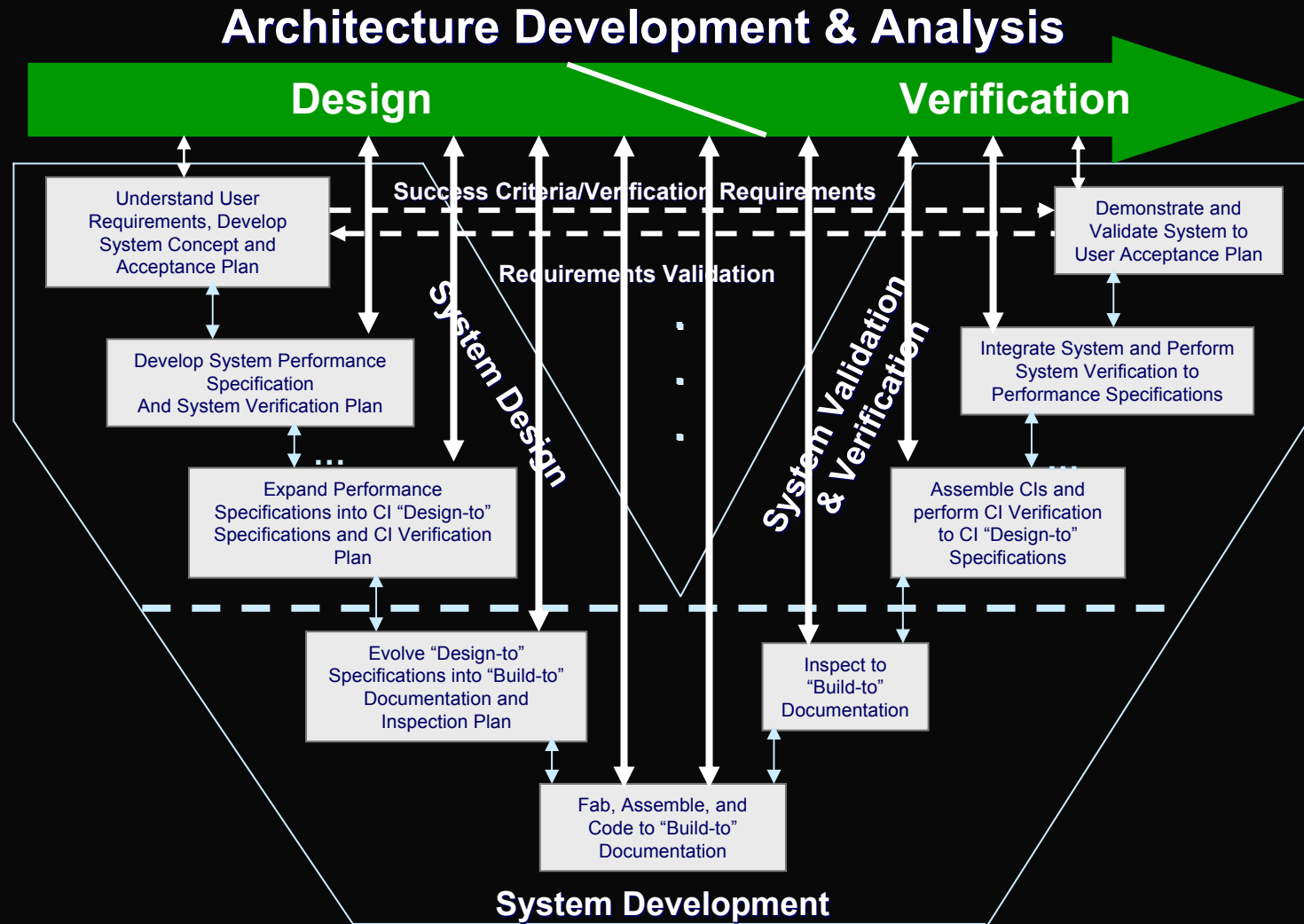
A few of the requirements lessons learned:

- **Must have a defined, or, at least understood, Operations Concept and Design Reference Mission**
- Be wary of :
 - Requirements for development of unproven technology. (i.e. are you going to have to invent something? – has it ever been done in orbit?) – especially in a human rated environment.
 - “Business” decisions that are a part of the contractors proposal – these are project risks.
 - A point design that has not been scrubbed in a requirements review by customers who understand the application and environment.

Systems Engineering “Vee”



Systems Management Office



Systems Analysis supports entire development cycle

Systems Analysis Activities*

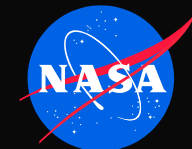


Systems Management Office

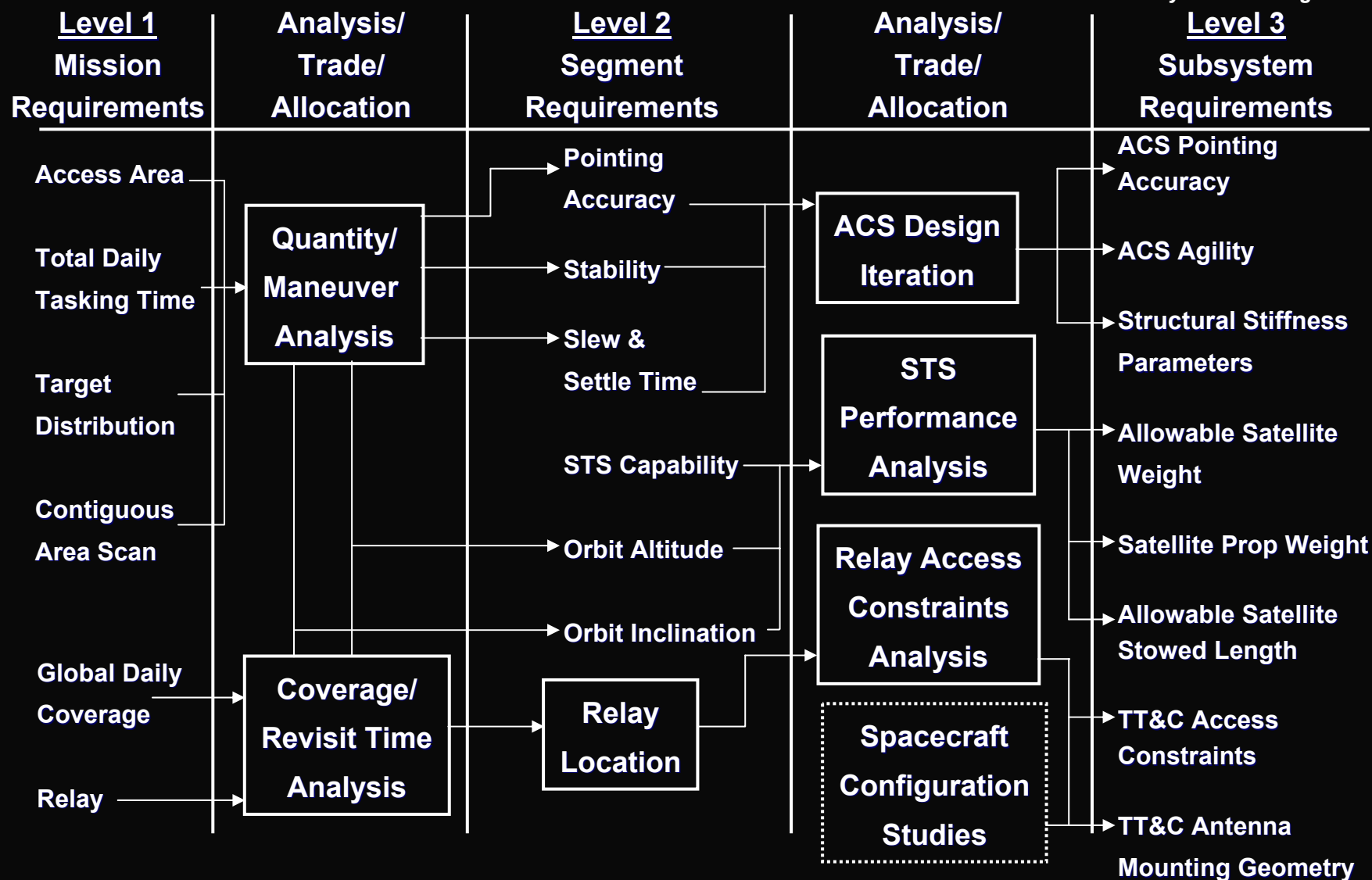
- Mission Requirements Derivation
 - Orbits/coverage
 - Ops scenarios/concepts
 - Mission figures of merit
- System Definition & Requirements Allocation
 - Orbit Selection
 - Coverage/visibility/connectivity
 - Payload performance requirements
 - Subsystem performance allocations
 - System timelines/resource allocations
- System Synthesis
 - Launch vehicle performance
 - Launch windows
 - Payload performance/operating scenarios
 - Performance analyses
 - Mission/system utility

* -- for a satellite system

Example of Mission Requirements Flowdown for a Satellite



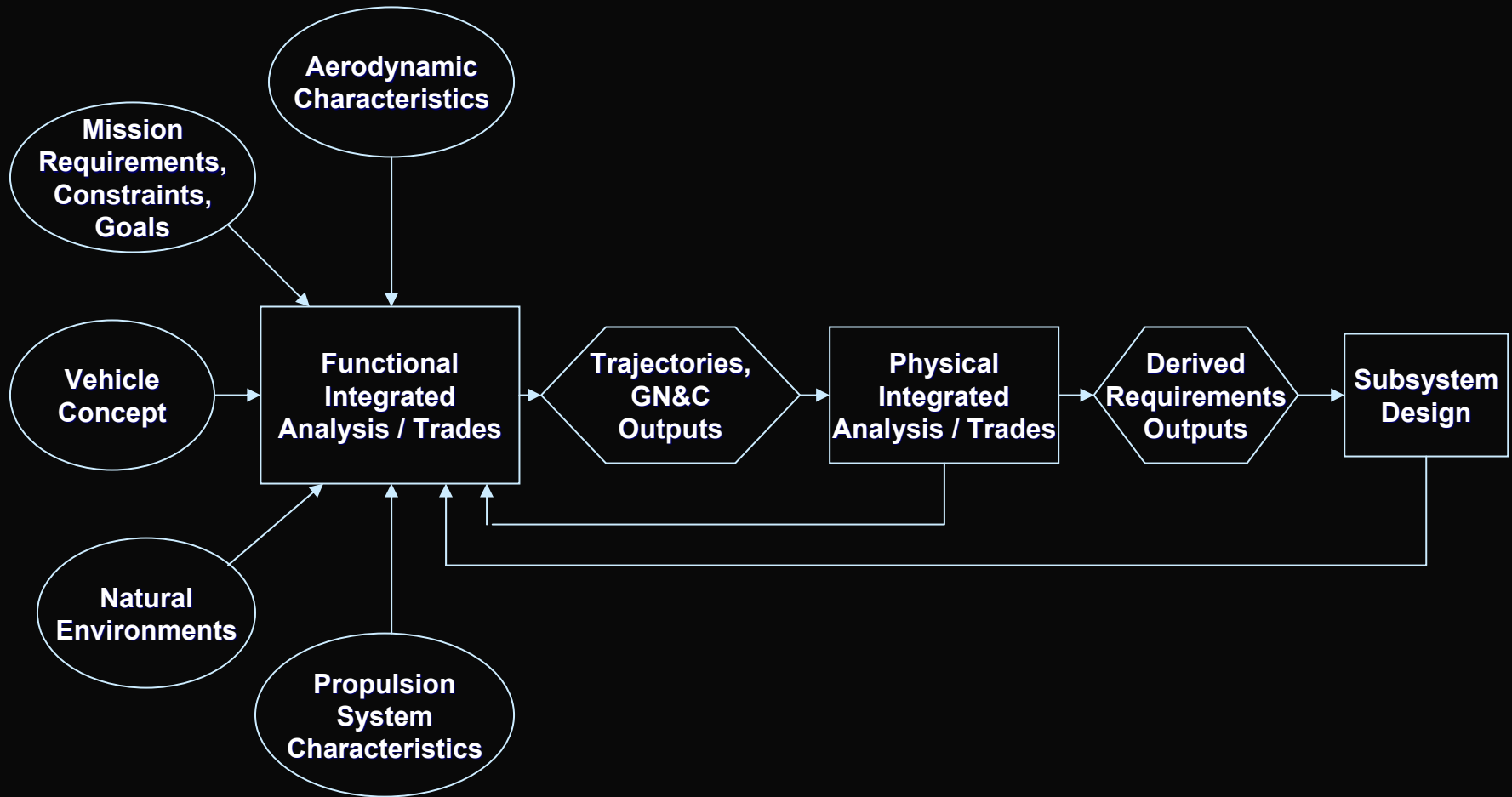
Systems Management Office



Launch Vehicle Analytical Integration and Subsystem Design



Systems Management Office



Systems Analysis Activities* (con't)



Systems Management Office

- System Optimization
 - Alternate designs
 - Performance and utility evaluation
 - Mission figures of merit evaluations
 - Error analysis
- System Verification
 - Analytical performance modeling
 - Detailed systems modeling
 - Performance verification by simulation
 - Subsystem Performance
- Engineering Specialties
 - System availability
 - Cost modeling
 - Survivability

* -- for a satellite system

Typical Systems Analyses for MSFC Projects



Systems Management Office

- Systems Analyses support systems requirements development and systems integration functions. Areas of analysis will be project-dependent, but some key analyses common to most projects along with responsible organizations include:
 - Functional Systems Analysis (Product Line Directorate)
 - Power Generation, Storage and Utilization Analysis (ED11/S. Luna)
 - Mass Properties Analysis (ED42/G. Jones)
 - Onboard Computer Timing and Memory Utilization Analysis (ED13/R. Humphries)
 - Attitude Control Propellant/Momentum Analysis (TD55/S. Ryan)
 - Propulsion System Performance Analysis (TD53/K. Holt)
 - Trajectory/Orbital Mechanics Analysis (TD54/F. Fogle)
 - Preliminary Equipment Layout (ED42/G. Jones)
 - Human Factors Analysis (ED42/ G. Jones)
 - Logistics/Supportability Analysis (ED42/ G. Jones)

 - (Continued next Chart)

Typical Systems Analyses for MSFC Projects



Systems Management Office

- (Continued from previous chart)
 - Engineering Cost Analysis (VS20/J. Hamaker)
 - Computer Software Requirements to Support Systems Operations (ED14/T. Crumbley)
 - Electromagnetic Compatibility/ Electromagnetic Interference Analyses (ED44/S. Rose)
 - Reliability and Maintainability (QS40 /A. Walker)
 - Thermal Analysis (ED25/L. Turner or ED26/P. Hunt)
 - Structural Analysis (ED22/ K. Spanyer)
 - Materials & Processes Analysis (ED35/S. Gentz)
-
- Products of these analyses will include not only performance predictions but resource budget allocations among system elements.

Technical Performance Measurement (TPM)



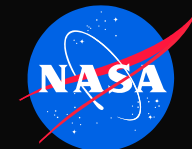
Systems Management Office

- TPM's are key system design parameters selected by the LSE and project team. System weight, volume and power are typical TPM's.
- TPM values have a powerful effect on the ability of the system to satisfy its intended function based on their impact on cost, schedule or technical performance.
- Too many TPM parameters trivialize management energy .
- Too few or the wrong parameters run the risk of missing indicators that could give forewarning of pending disasters.
- The LSE may allocate selected TPM values to subsystems or across interfaces, while holding a reserve that decreases as the design matures.
- TPM's and trend data should be reported regularly (monthly, quarterly, etc.), whereas at every design review a "Requirements vs. Capability" table must be included as a review deliverable. This table contains column headings of Requirement, Projected Capability, Resulting Margin, and Basis for Stated Capability (e.g. analysis, test, already performed or projected).



TPM / Capability Matrix Examples

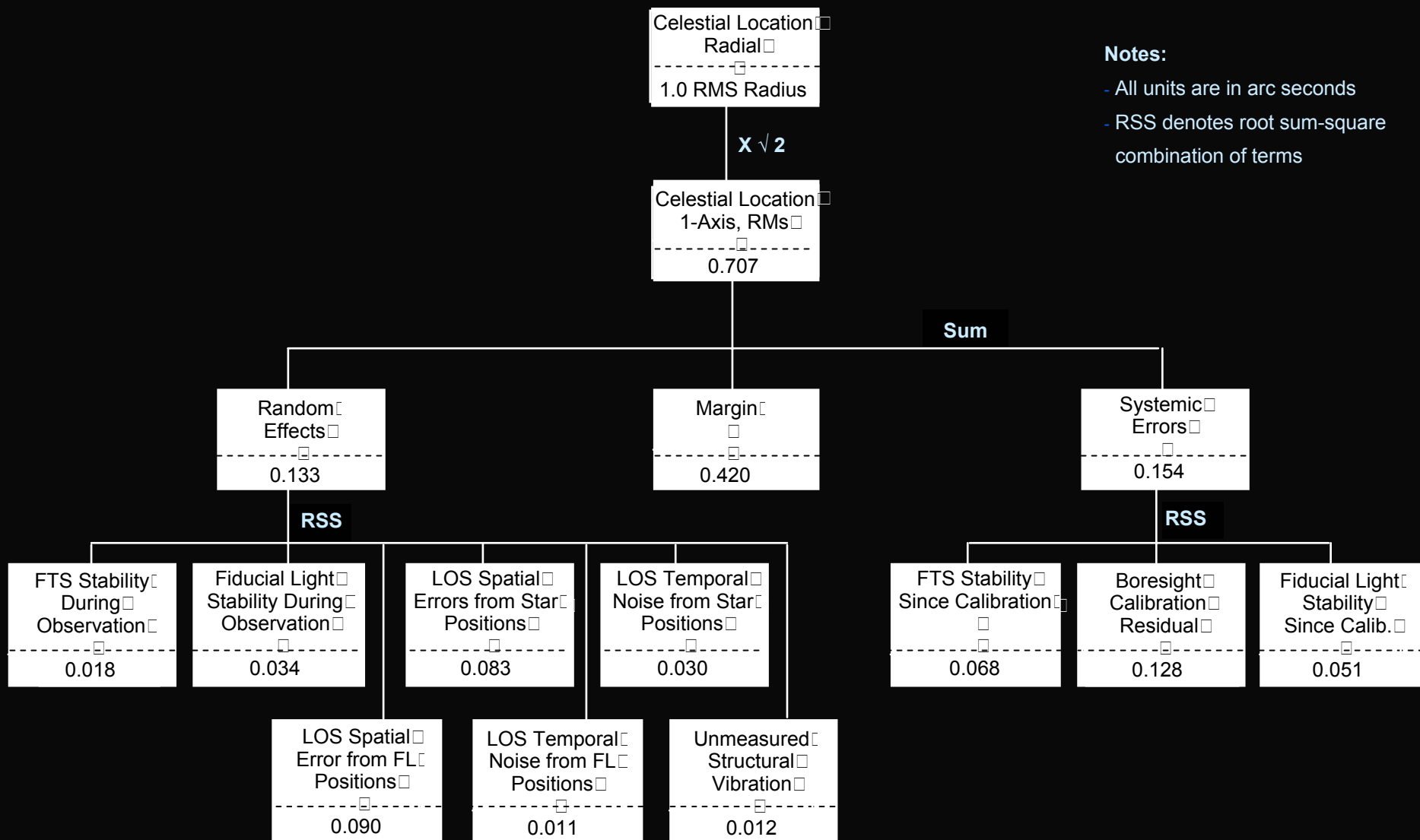
Celestial Location Error Budget/Measurement Worksheet



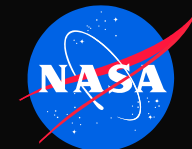
Systems Management Office

Notes:

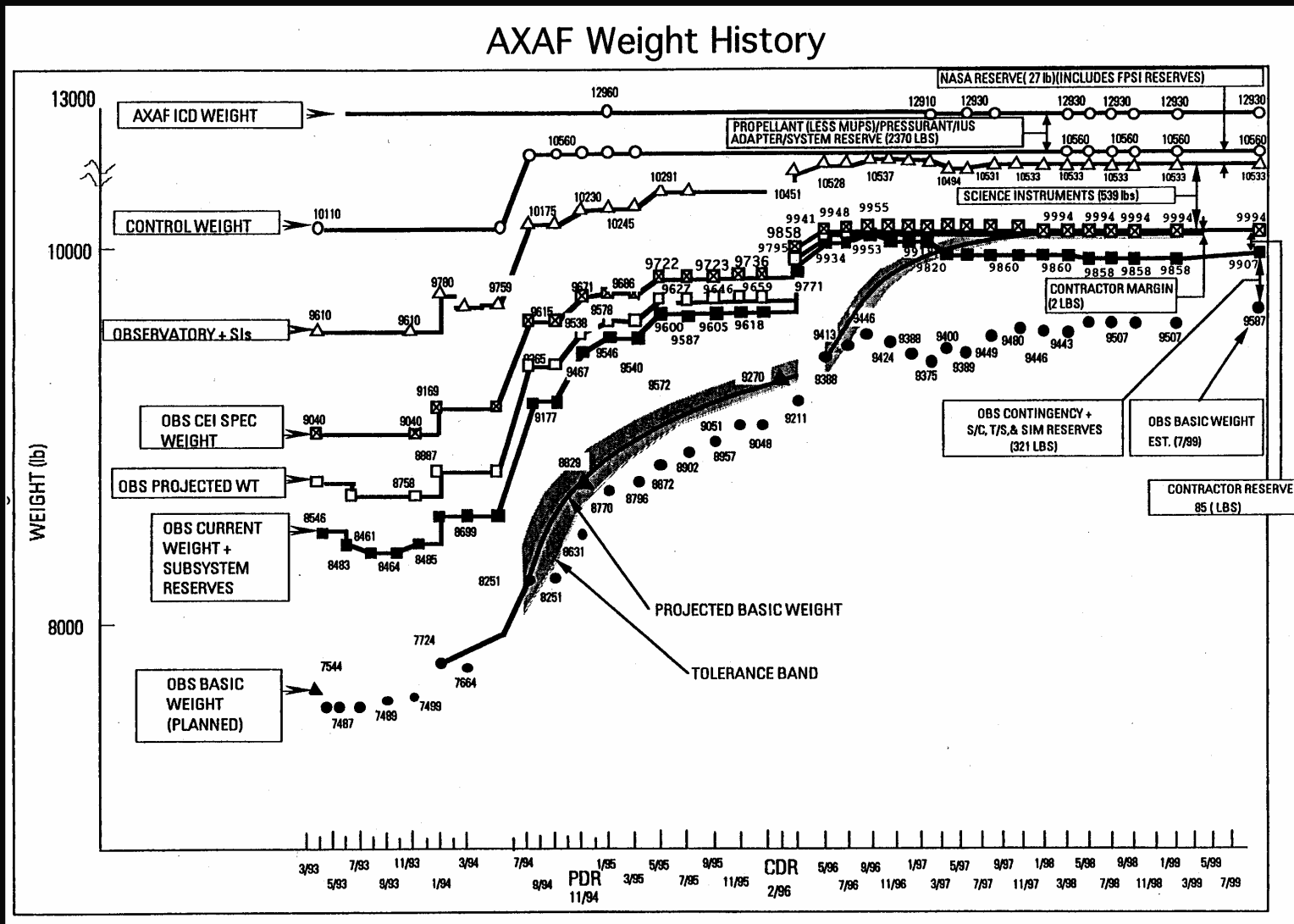
- All units are in arc seconds
- RSS denotes root sum-square combination of terms



Chandra Weight History



Systems Management Office



DMLAE Requirements vs. Capabilities



Systems Management Office

Parameter	Requirement	Demonstrated Capability
Steady State Thrust	102 ± 2 lbf at regulated pressure	102 ± 2 lbf at nominal inlet pressures of 220 psia
Steady State Specific Impulse	314.5 sec. nominal, 312 sec. minimum	314.5 ± 2 seconds
Oxidizer to Fuel Mixture Ratio	1.07 ± 0.02	1.07 ± 0.02
Steady State Continuous Operation	1000 seconds	3600 seconds
Total Steady State Operation	3000 seconds	24, 430 seconds
Engine Starts	12	25
Thrust Vector Alignment	Geometric thrust vector within 0.25° to the plane of its mounting interface	0.25°



Trade Studies

- Purpose: provide an objective foundation for the selection of one or more approaches for the solution of an engineering problem.
- Multiple ways to accomplish, but all have common characteristics:
 - Minimum requirements to be achieved defined
 - Viable alternatives that satisfy requirements
 - Selection criteria (e.g., Cost, schedule, technical)
 - Metrics for evaluating alternatives
 - Weighting factors for each criteria
 - Ranking/scoring process

Trade Studies: Basic Approach



Systems Management Office

Define trade objectives

- Go/no-go criteria
- “Musts”, not “wants”

Determine alternatives

- Design options (2 or more)
- Comparable maturity

Define evaluation criteria/weights

- Characteristics key to customer
- Usually, cost, schedule, technical
- (various)

Collect metrics

- Quantitative measures or
- Engineering judgment

Rank/score alternatives

- Arithmetic
- Statistical

Trade Studies: Objectives

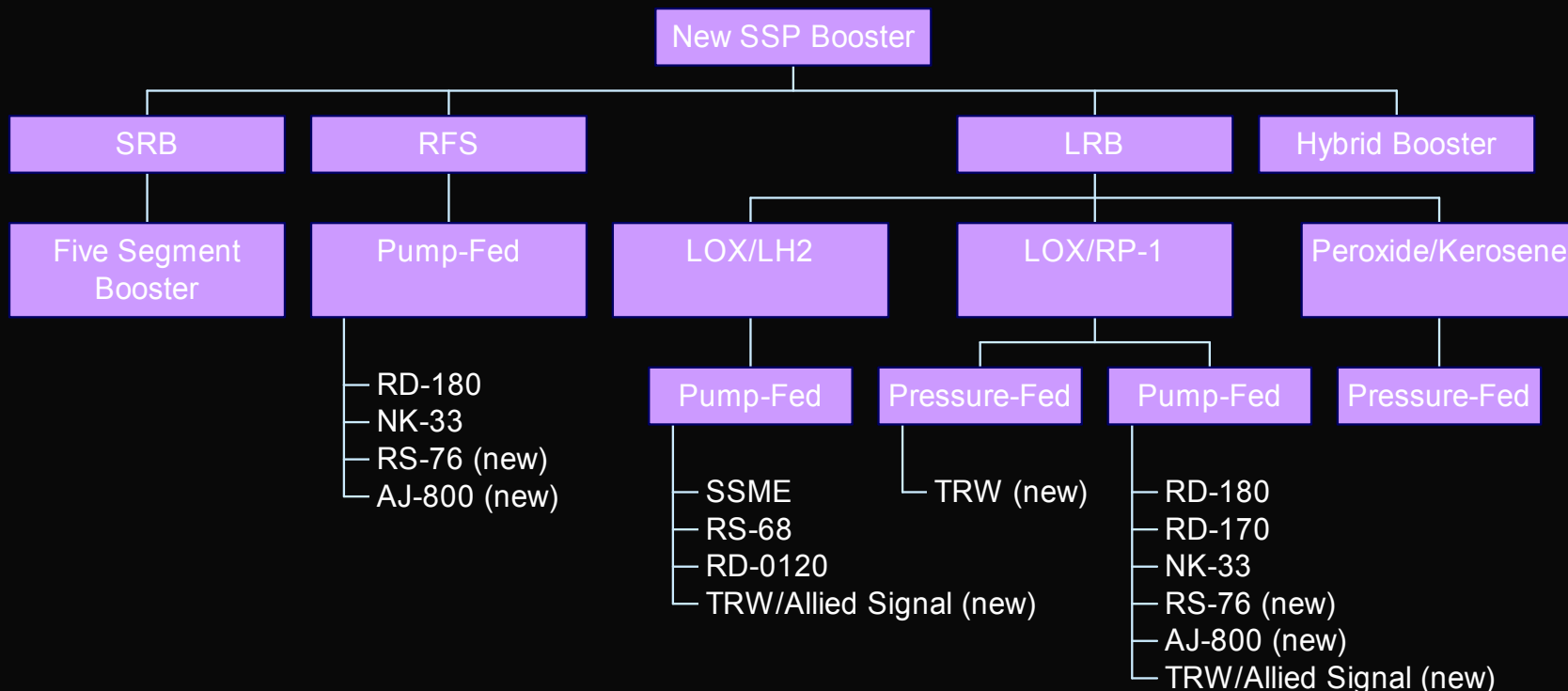


Systems Management Office

- **Minimum requirements to be achieved**
 - What are mandatory capabilities or characteristics ?
 - e.g., Weight < xxx lbs., Isp > 400 sec., etc.
 - “Musts”, not “wants”
 - Confirm with customer/user
 - Clearly communicate to team
- **Example (from SRB TVC trade study):**
 - *Provide a measurable improvement in SRB flight safety and reliability*

- **Viable alternatives that satisfy requirements**
 - Must meet go/no-go criteria
 - Generally 4 - 7 alternatives
 - Comparable design maturity
- **Example: (from Solid Rocket Booster TVC trade)**
 - *Electric APU*
 - *Helium APU*
 - *Recummulation*
 - *Blowdown*

- A “Trade Tree” is a useful tool for depicting the trade space, including “trades within trades”
- Example: Alternate Booster Options & Candidate Engines



Trades Studies: Evaluation Criteria



Systems Management Office

- **Establish evaluation criteria**
 - Key desirable characteristics
 - What is important to customer
 - Usually cost, schedule, technical (various)

- **Example (from SRB TVC trade):**
 - *Reliability*
 - *Recurring cost*
 - *Supportability*
 - *Schedule to first flight*

Trade Studies: Criteria Weighting



Systems Management Office

- Weighting factors
 - Reflection of customer needs
 - Independent of technical assessments
 - Usually done as %
 - May be used for sensitivity analyses
- **Example (from SRB TVC trade)**
 - *Flight safety/reliability* 25%
 - *Ground safety* 15%
 - *Schedule* 15%
 - *Supportability* 15%
 - *Technology/integration* 15%
 - *Cost* 15%

- Metrics for evaluating alternatives against criteria
 - Quantitative metrics desired
 - (e.g., Weight, thrust, reliability)
 - Engineering judgment otherwise
 - (e.g., Supportability, design complexity)
 - Consider indirect measurement
 - (e.g., Parts count, number of interfaces, processing hours)
- **Example: (from SRB TVC trade)**
 - *# Of criticality-1 failure modes*
 - *Launch processing hours*
 - *Technology readiness level*

Trade Studies: Scoring



Systems Management Office

- Scoring and ranking
 - Typically, spreadsheet scoring is sufficient
 - Cardinal or ordinal approach typical
 - Ordinal = straight ranking (e.g., 1,2,3,4,5,...)
 - Cardinal = relative values assigned (e.g., 1-10)
 - Rank according to assigned scores/weights
 - If necessary, apply appropriate statistics (e.g., Analysis of Variance)
 - Formulate clear recommendation
 - Validate with engineering judgment
 - Present clear recommendation(s) and rationale
 - May not be single recommendation
 - Understand strengths and weaknesses of each option

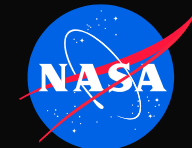
Trade Study Example: ISS Propulsion Module Trade Study



Systems Management Office

In the Spring of 2000, the Alternate Propulsion Module Assessment Team (APMAT) was formed to study alternatives to the existing ISS Propulsion Module baseline.

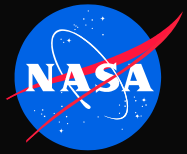
Basic Trade Study Methodology



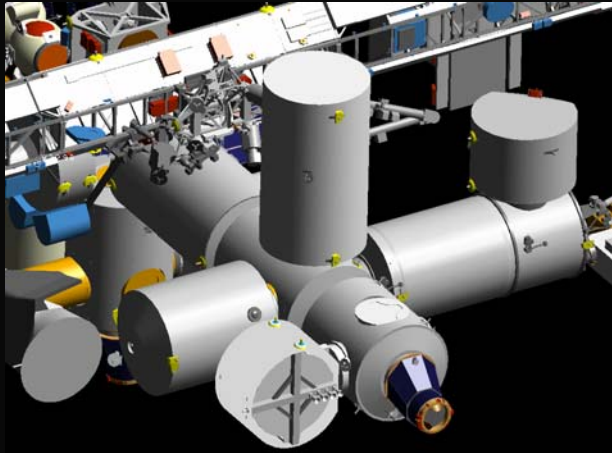
Systems Management Office

- The basic methodology is to select the optimum Propulsion Module design approach based upon weighted scoring of each option against:
 - The five basic driving requirements (go/no-go)
 - Weighted assessment criteria (33 total)
 - Other mission goals and constraints
- Two fundamental design questions/issues.
 - Basic propulsion system design
 - Monopropellant vs. bi-propellant
 - Propulsion Module packaging & location on ISS and quantity of Propulsion Modules required over ISS life

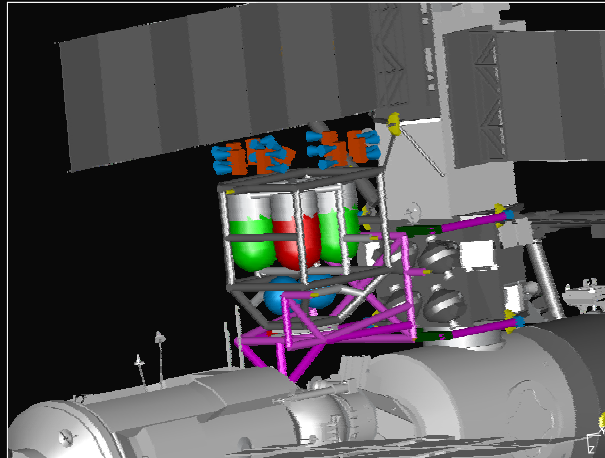
Concepts Assessed



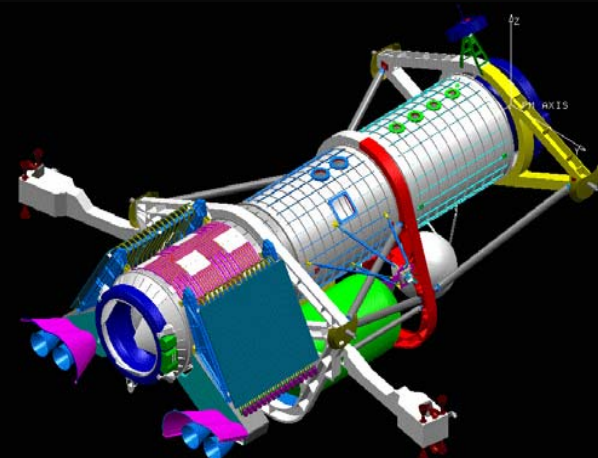
Systems Management Office



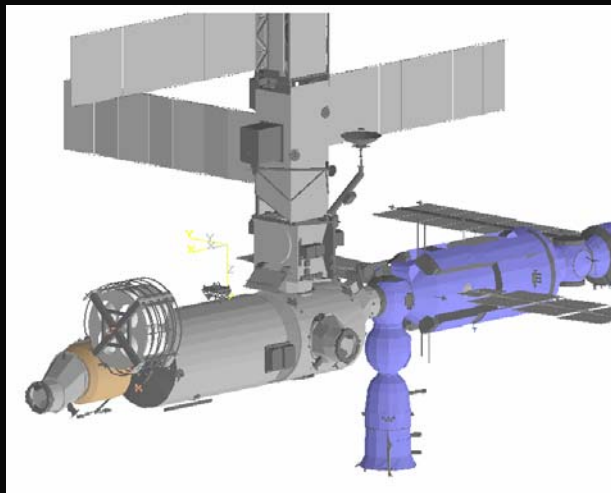
Node X



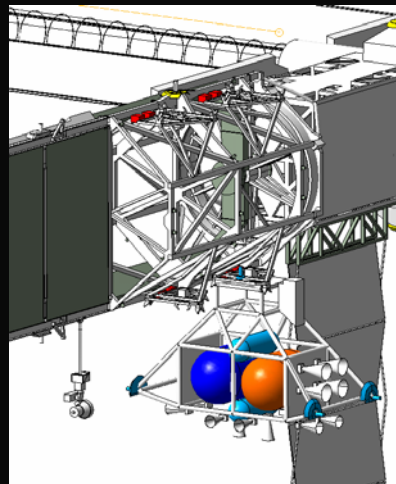
Z1 Truss



***Modified Baseline
Option 2***



Split Element

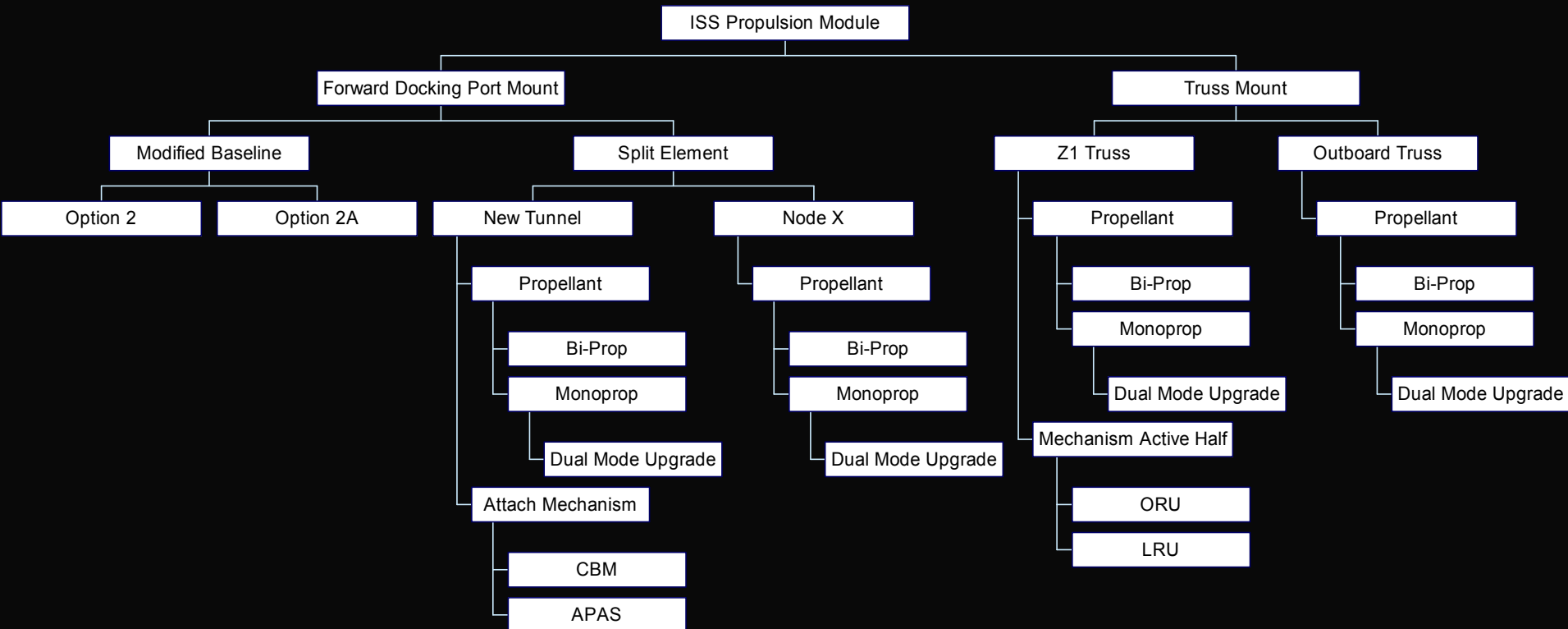


***Outboard
Truss***

ISS PM Study Trade Tree



Systems Management Office



System Analysis Process



Systems Management Office

- Defined 33 criteria within three broad categories
 - Programmatic: 5
 - DDT&E: 13
 - Integration: 15
- Empirically assessed each option against each criteria
- Analysis Method
 - Analysis of Variance by Ranks within each category (Programmatic, DDT&E, & Integration)
 - Key discriminant analysis

Assessment Criteria & Weighting



Systems Management Office

- Programmatics (60%)
 - Cost
 - Schedule
 - Risk
- DDT&E (20%)
 - Safety
 - Design Complexity
 - Design Pedigree
 - Resources
 - Performance effectiveness
- Integration (20%)
 - ISS Impacts
 - Shuttle Impacts
 - Verification
 - Activation complexity
 - Returnability
 - Logistics

Sample Criteria Scoring



Systems Management Office

Empirical Data for Options against Criteria

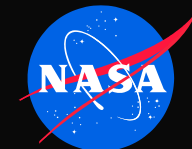
<u>Criteria</u>	<u>Option 2 Rating</u>	<u>2A Rating</u>	<u>Split Element Rating</u>	<u>Node X Rating</u>	<u>Z1 Truss Rating</u>
electrical power	Average Power = 907 w, Peak Power during reboost = 2479w during reboost	Average Power = 907 w, Peak Power during reboost = 2479w during reboost	AV = 1151W, PK = 1955W	Average Power = 2.0kw, Peak Power 3.5kw	Avg = 1067 W Peak = 1955W



Ranking of Options against Criteria

<u>Criteria</u>	<u>Mod B/L 2</u>	<u>Mod B/L 2A</u>	<u>SE</u>	<u>NX</u>	<u>Z1</u>
electrical power	1	2	4	5	3

Relative Ranks of Options



Systems Management Office

Category	Criteria	Mod B/L 2	Mod B/L 2A	SE	NX	Z1
Schedule	Development Schedule	1	5	3	3	3
Cost	Development	4	5	3	2	1
	Life Cycle	5	4	2	3	1
Risk	Cost	4	5	3	2	1
	Schedule	3	5	4	1.5	1.5
AVERAGE		3.4	4.8	3	2.3	1.5
Safety	Shuttle	4.5	4.5	2	2	2
	ISS	4	5	3	1	2
Design Complexity	mechanisms	3	5	1	4	2
	on-orbit interfaces	1	5	3	3	3
	component count	2	4	3	5	1
Design Pedigree	design heritage	3	5	3	1	3
Resources	electrical power	1	2	4	5	3
	data	4	5	2	3	1
	thermal	3	3	3	3	3
	EVR maintenance	3	3	3	3	3
	EVA maintenance	2.5	2.5	2.5	2.5	5
	IVA maintenance	4.5	4.5	2.5	2.5	1
Performance Effectiveness	prop budget	1.5	1.5	4	4	4
	maintainability	1	5	2.5	2.5	4
AVERAGE		2.7	3.9	2.8	3.0	2.6

Note: 1 is best, 5 is worst

Relative Ranks of Options (con't.)



Systems Management Office

	Category	Criteria	Mod B/L 2	Mod B/L 2A	SE	NX	Z1
Integration	ISS Impacts	Assembly sequence	3	3	3	3	3
		plume effects	1.5	1.5	3.5	3.5	5
		science payloads	3	3	3	3	3
		reboost attitude	2.5	2.5	2.5	2.5	5
		PM/ISS interfaces	3.5	3.5	3.5	3.5	1
	Shuttle Impacts	PM function when shuttle	4.5	4.5	2	2	2
		PM/Shuttle interfaces	3.5	3.5	3.5	3.5	1
	Verification	Thermal vacuum test	3	3	3	3	3
		acoustic test	3	3	3	3	3
	Activation Complexity	EVA manhours	3.5	3.5	1.5	1.5	5
		EVR hours	3.5	3.5	1.5	1.5	5
	Returnability	EVA manhours	4.5	4.5	2	2	2
		EVR hours	5	4	1.5	1.5	3
	Ground Ops	turn-around time	4.5	4.5	2	2	2
	Logistics	shuttle flights over life cycle	5	4	2	2	2
AVERAGE			3.6	3.4	2.5	2.5	3.0

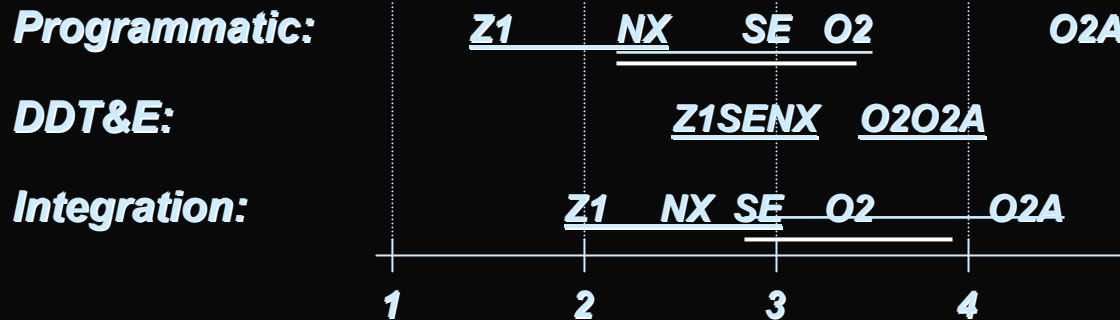
Note: 1 is best, 5 is worst

Comparative Rankings of Options



Systems Management Office

Analysis of Variance (ANOVA) Results



Options not underscored differ significantly w/95% confidence.

Sums of Weighted Ranks

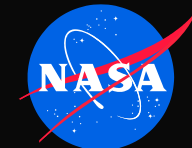
	Mod B/L 2	Mod B/L 2A	SE	NX	Z1
Programmatic (60%)	3.4	4.8	3.0	2.3	1.5
DDT&E (20%)	3.7	3.9	2.8	3.0	2.6
Integration (20%)	3.6	3.4	2.5	2.5	3.0
Composite	3.5	4.3	2.9	2.5	2.0

• The Z1 Truss Option has the overall lowest weighted rank sum.



Trade Study Backup Charts

Requirements



Systems Management Office

1. Provide for the total on demand ISS Attitude Control and ISS Orbit Maneuver Control [Total Impulse/Year]
 - ISS Attitude Control
 - Visiting vehicle proximity operations & dockings (i.e. Shuttle, Soyuz, Progress, ATV, HTV)
 - Attitude maneuvers
 - Attitude hold
 - During translation/orbit maneuvers
 - CMG reset/desaturation
 - ISS Orbit Maneuver Control
 - Altitude maintenance (reboost)
 - Debris avoidance maneuvers
 - *Note: requirement varies with time due to solar cycle*
 - Reserve Propellant Capability (a.k.a. “Skip” Cycle Capability)
 - *Note: requirement varies with time due to solar cycle*

Requirements (continued)



Systems Management Office

2. Location to be on the US Segment

- Configuration 6A Supportability

3. Fault Tolerance

- Safety: Two Fault Tolerant
- Functionality: One Fault Tolerant

4. Station Constraints

- Preserve Two STS Docking Port Access
- Preserve services between ISS and docking/berthing element

5. Initial capability shall provide 50% of the total propulsion requirement on average for the life of ISS [Availability through AC + 10 years].

- Defines “nominal” use case
- Growth path to 100% ISS propulsion capability must be described



Integration and Operations

In August, 2000, only 64% of the MSFC projects surveyed had documented processes for mechanical, electrical, thermal and system design integration.

Integration and Operations



Systems Management Office

- ***System Integration*** - Physical and functional integration activities necessary to complete assembly and verification of the system.
- ***Ground Operations*** - Pre-launch/Post landing activities at the launch/landing site.
- ***Mission Operations*** - On-orbit operation and support of the system.

- Designer responsibility generally ends with acceptance of component/subsystem.
- System engineering must ensure elements are properly integrated, physically and functionally, including:
 - System compatibility analyses/analytical integration
(e.g., EMI/EMC, layouts, contamination, pointing/error budget, etc.)
 - Interface definition and control
 - Integration planning/scheduling
 - Timely delivery of components
 - Coordination with test engineer

Interface Definition and Control



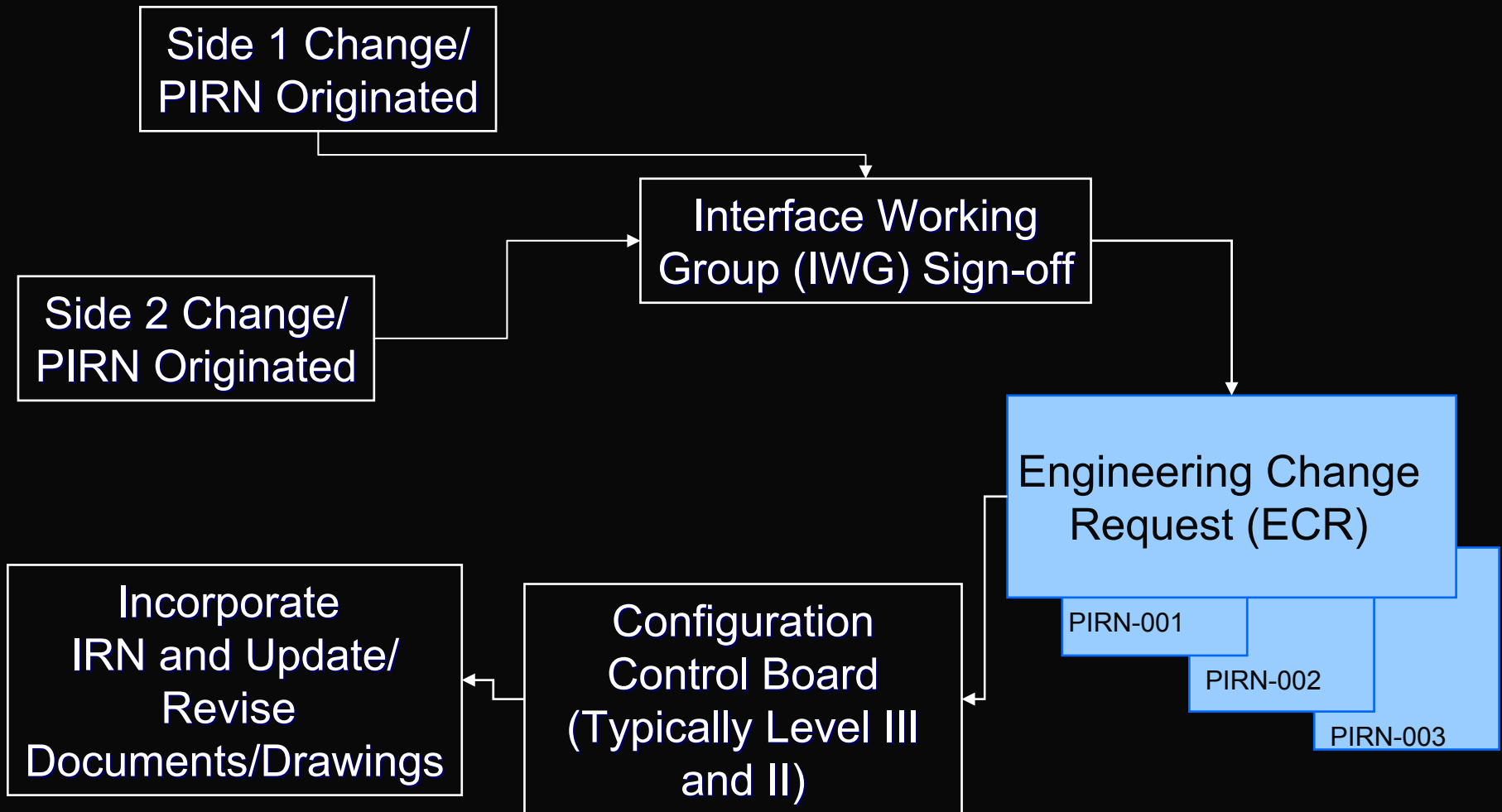
Systems Management Office

- **Interface Control Process Activities (All defined in MSFC-HDBK-1912)**
 - Project Milestone Reviews (SRR, PDR, CDR...)
 - Configuration Control Boards (CCB)
 - Technical Interchange Meeting (TIM) & Interface Working Group (IWG)
- **Interface Terminology**
 - **Interface Requirements Document “IRD”** (Design To “Shalls” found in Systems Requirements Document or Interface Requirements Document)
 - **Interface Control Document “ICD”** (Design “Solution” to requirements, Bilateral agreement signed by both interfacing parties controlled by Program/Project Manager)
 - **Interface Definition Document “IDD”** (Design “Solution” to requirements, Unilateral document controlled by end-item provider “One Sided ICD”)
 - **Preliminary Interface Revision Notice “PIRN”** (Early notification to interfacing parties of potential interface change worked through the IWG)
 - **Interface Release Notice “IRN”** (Formal “worked” notification through CCB to interfacing parties of approved change issued by CCBD)
 - **Systems Requirements Document “SRD”** (Design to “Shalls”)

Interface Control - PIRN/IRN



Systems Management Office



Interface Control - Lessons Learned



Systems Management Office

- **Interface Requirements should be found in one of two places (Systems Requirements Document or Interface Requirements Document)**
- **Combining IRD into ICD saves a little in document preparation but costs a lot in confusion and complicates the baselining and verification process**
- **Baselining ICD too early (e.g., at PDR) can cause unnecessary Formal change traffic PIRNs/IRNs**
- **Coordination via TIMs and IWGs cannot be overemphasized**
- **If Interface is Critical/Complicated, ICDs should be developed**
 - **Contractor to Contractor**
 - **Contractor to NASA**
 - **NASA to NASA (Different Centers)**
 - **NASA to NASA (Within Center)**
- **Interface Requirements Document and Interface Control Document Data Requirement/Description**
 - **<http://masterlist.msfc.nasa.gov/drm/>**

Ground Operations & Logistics



Systems Management Office

- **Addresses planning for overall physical support of hardware from completion of manufacture through its' life cycle**
 - **Transportation**
 - **Ground Support Equipment (GSE) requirements**
 - **Checkout and maintenance support**
 - **Launch site requirements**
 - **Spares planning**
 - **Maintenance predictions/planning**
 - **Facility support requirements**
- **Early supportability assessment can reduce life cycle costs**
- **Depending upon project scope, products may include:**
 - **Ground operations plan**
 - **Integrated logistics support plan**
 - **Ground support equipment requirements**
 - **Operations and maintenance manuals**

Mission Operations Planning is a critical part of Project Planning since it defines the functional requirements for operations, defines the interface between operations facilities and flight systems, and defines the resources and schedule required to execute the operations.

Flight Operations and Support includes:

- Functional Objectives development
- Telemetry and Command support
- Ascent/Orbit/Reentry
- Command and Display Requirements
- Timeline Development
- KU & S Band Coverage
- How to design for Human Factors
- Orbital Requirements and Constraints
- Training Support
- Crew Training and Crew Procedures
- SIM and JIS support
- Mission Support (Infrastructure)
- Data Disposition



Safety and Mission Assurance

Safety and Mission Assurance



Systems Management Office

- Project Assurance
 - Independent functions provided by S&MA Office
 - Safety
 - Quality Assurance
 - Reliability and Maintainability
 - OPR for Center risk management process
- Lead Systems Engineer responsible for ensuring incorporation of S&MA requirements and recommendations.

- Quality Assurance
 - Ensures delivered system meets project quality requirements
 - Early definition of Quality Requirements/QA Plan
 - Quality system and process audits
 - Procurement Quality requirements
 - Letter of Delegation for In-plant surveillance
 - Test surveillance at MSFC
 - Physical inspections
 - Data review
 - Designing for Maintainability

Safety and Mission Assurance



Systems Management Office

- Quality Plan Specifies:
 - Quality practices
 - Resources required
 - Sequence of activities to be performed
- Quality Requirements Includes:
 - Nonconformance reporting
 - Inspection requirements
 - Material Review Board Process (Use-as-is, scrap, use-as-repaired)
- Procurement Quality Requirements
 - Important to maintain process control at vendor (I.e. no unauthorized changes), nonconformance reporting requirements, MRB

- Reliability and Maintainability
 - Early support in definition of R & M requirements
 - Development of predictions and design assessments (Per MWI 7120.6)
 - Type 3 - Fault Tree, Hazard Analysis
 - Type 2 - Fault Tree, Hazard, Failure Modes and Effects Analysis
 - Type 1 - Fault Tree, Hazard, Failure Modes and Effects Analysis, Probabilistic Risk Assessment
 - Develop Reliability and Maintainability analyses
 - FMEA may identify single failure points which require redesign or more stringent verification methods
 - Early assessments needed to minimize operations and maintenance costs

Safety and Mission Assurance



Systems Management Office

- Safety
 - Provides overall Flight and Ground Safety support to project
 - Development of project Safety Plan
 - Safety Plan describes how safety requirements will be met. Emphasizes how hazards will be identified, eliminated or controlled, integrates and describes the relationship between safety activities.
 - Development/Review of Hazard Reports
 - Identify hazard causes
 - Develop hazard controls
 - Develop verifications to ensure controls are in place
 - Coordination with JSC and KSC Safety Panels
 - Facilitates MSFC Payload Safety Readiness Review Board
 - Support Lead Systems Engineer in resolution of Safety concerns
 - Industrial safety support
 - Safety Engineer must be an integral part of Project team from “Cradle to Grave”



Project Technical Penetration and Risk Management

Program/Project Penetration



Systems Management Office

- **Definition**

- Having the Right Programmatic and Technical Expertise Strategically Engaged asking the Right questions. “Exploring why it won’t work”

- **Assumptions**

- Program/Project is ultimately responsible to Center for defining “Acceptable” Level of Risk (anything less than Complete Oversight adds “Additional” risk to activity)
- Program/Project team with ED, SMO, S&MA...to satisfy the “Penetration Requirements” found in MPG 7120.1/NPG 7120.5 (see backup chart)
- We can use existing MSFC ISO/NASA Processes to do the Job
 - Program/Project Planning MPG-7120.1
 - Systems Engineering MSFC-HDBK-3173 and SP6105
 - CWC Process

Program/Project Penetration



Systems Management Office

- **Goal**

- Enhance the probability of mission success for MSFC programs with limited government workforce and resources through all phases, e.g., Concept Definition, Acquisition, SRR, PDR, DCR, FRR, Operation, and Anomaly Resolution

- **Strategy**

- Deploy workforce with emphasis on highest risk areas
 - Project/Engineering/Safety consensus on risk areas
 - Establishment of risk mitigation plans
- Utilize risk management approach and apply **Penetration Levels** based on level of risk of each area
 - High Risk Areas = Higher Penetration
 - Low Risk Areas = Lower Penetration
- Penetration levels will be adjusted as risk areas and their severity change over the life of the project
- Penetrate to a level that assures the performing organization is doing the right things

Program/Project Penetration



Systems Management Office

Penetration Levels (by discipline areas)

Level 0 - No Penetration

- Accept performing organization's tasks at face value (based on assessment that no penetration is required)

Level 1 - Low Penetration

- Participate in reviews and Technical Interchange Meetings and assess only the data presented
- Perform periodic audits on pre-defined process(es)
- Chair board or serve as board member, or RID writer, at a formal review
- Participate in resolution and closure of issues

Level 2 - Intermediate Penetration

- Includes low penetration with addition of:
 - Daily or weekly involvement to identify and resolve issues

Level 3 - In-depth Penetration

- Includes intermediate penetration with addition of:
 - Methodical review of details
 - Independent models to check and compare vendor data, as required

Level 4 - Total Penetration

- Perform a complete and independent evaluation of each task

Program/Project Penetration Insight Continuum



Systems Management Office

No Penetration

Total Penetration

Level 0

Level 1

Level 2

Level 3

Level 4

Review of
Processes

Review of
Process **and**
Implementation

Increasing technical penetration

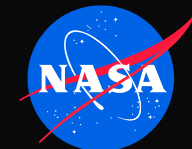
Did they do the
right things?

Did they do the
right things
and did they
do them right?

Level of insight contingent on defining an acceptable risk:

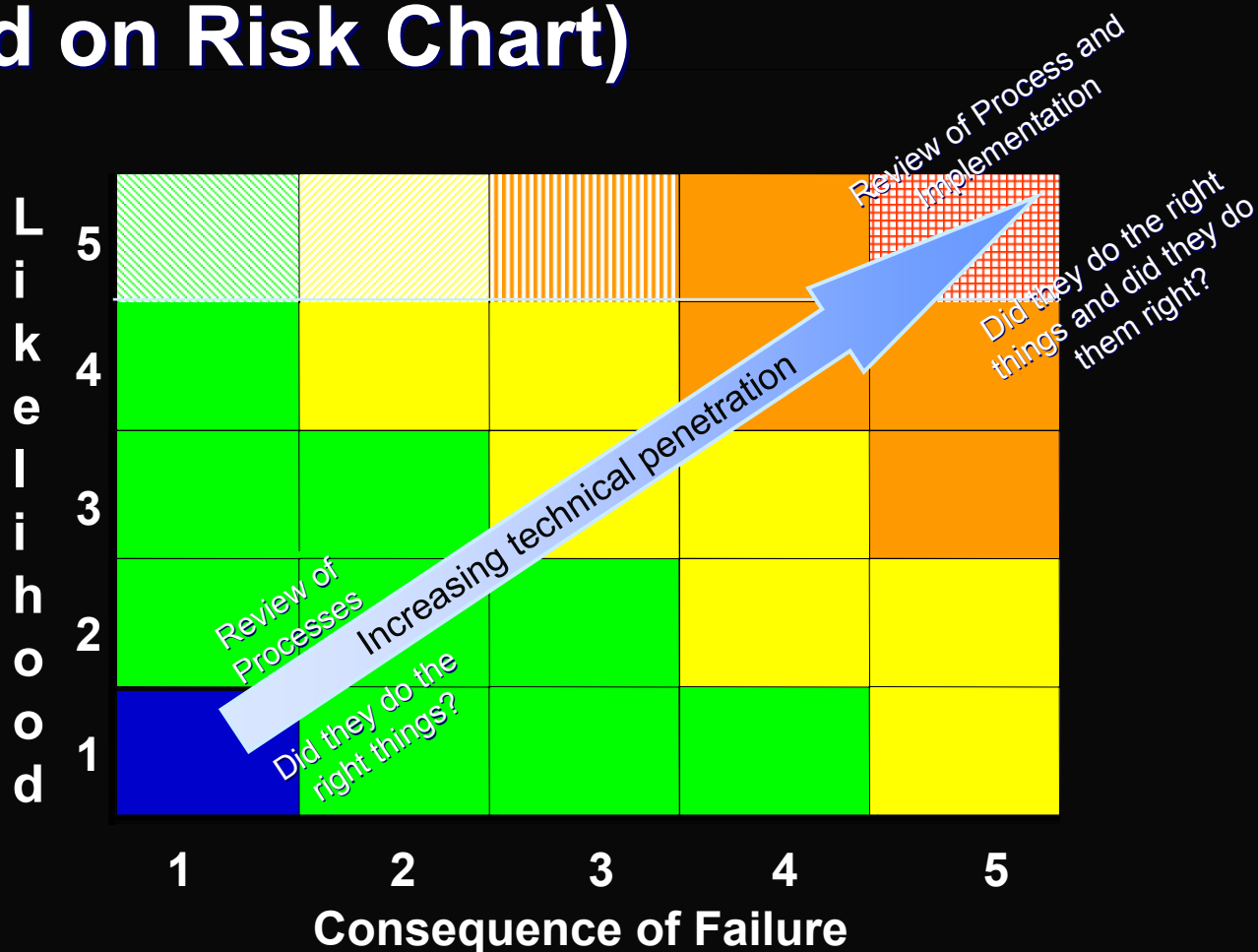
- Technical risk levels
- Amount of trust in performing organization's abilities
- How well processes are defined
- Level at which NASA is performing Collaborative Work Commitments (CWC's) for the program
- Human rating of vehicle
- Program visibility and impact of failure
- Design complexity, manufacturing complexity, producibility
- Value of asset

Program/Project Penetration



Systems Management Office

Penetration Assessment Matrix (Mapped on Risk Chart)



Program/Project Penetration



Systems Management Office

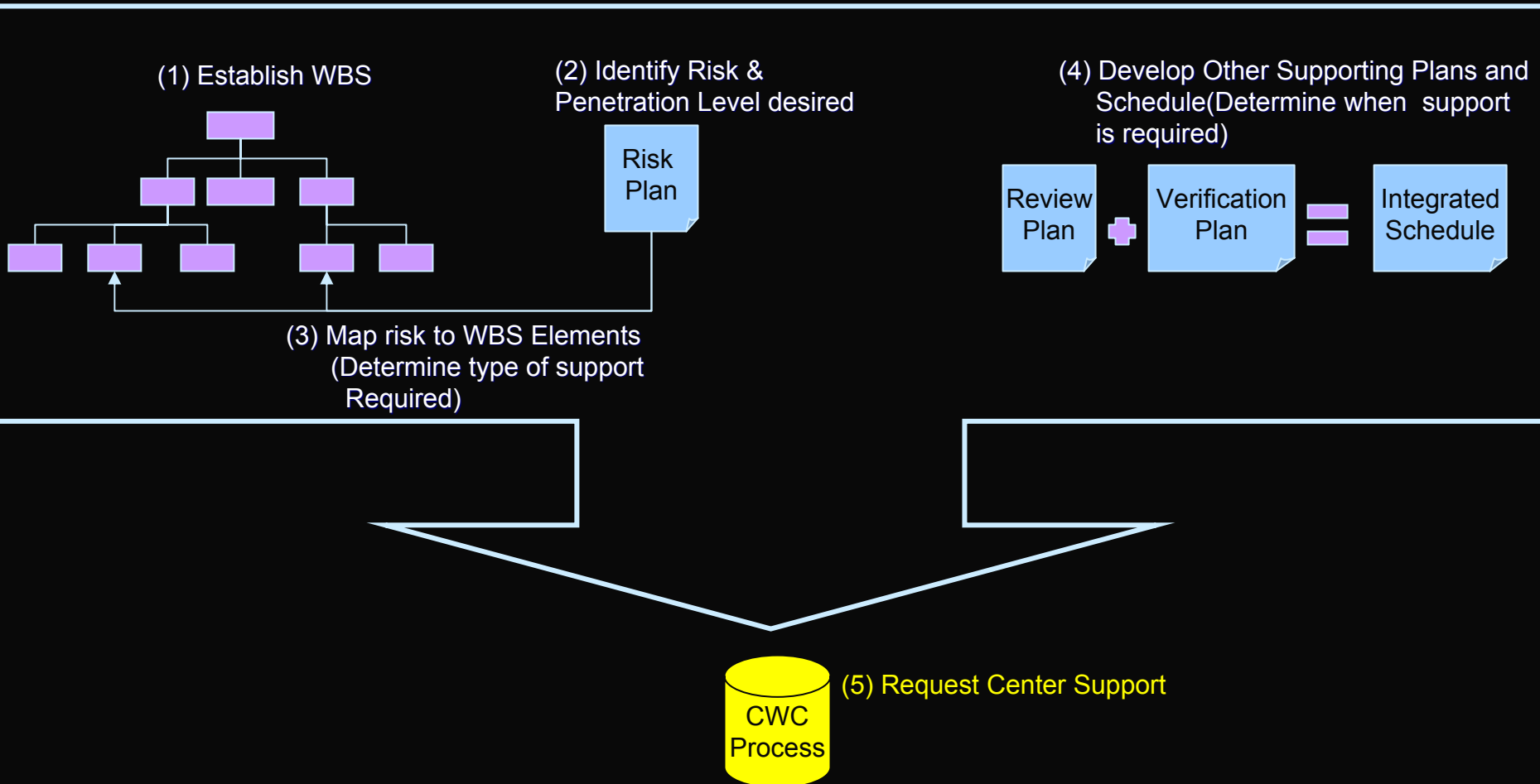
Example of Insight Matrix		ENGINEERING SERVICE																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																								
		Electrical Power	Instrumentation and Control		Computers and Data Systems		Flight Software	Avionic Systems	EEE Parts and Packaging		Control Electronics	Radio Frequency (Tracking, Telemetry, Comm)		Avionics Simulation	Structural and Dynamic Loads		Strength Analysis		Structural Design	GSE and Mechanisms Design		Thermodynamics and Heat Transfer		Thermal and Fluid Systems		Structural and Dynamics Testing		Environmental Effects		Non-Destructive Eval and Tribology		Metallic Materials and Processes		Non-Metallic Materials and Processes		Project Engineering		Chemistry (Compatibility, Analytical & Environment.)		Manufacturing Services		Special Test Equipment Design (Struct./Mech, Piping)		Sys Engr Support (Analysis, Modeling, Human Engr)		Configuration and Data Management		Environments (EEE, Aerospace Environ)																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																										
AREA OF PENETRATION																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																										

Program/Project Penetration



Systems Management Office

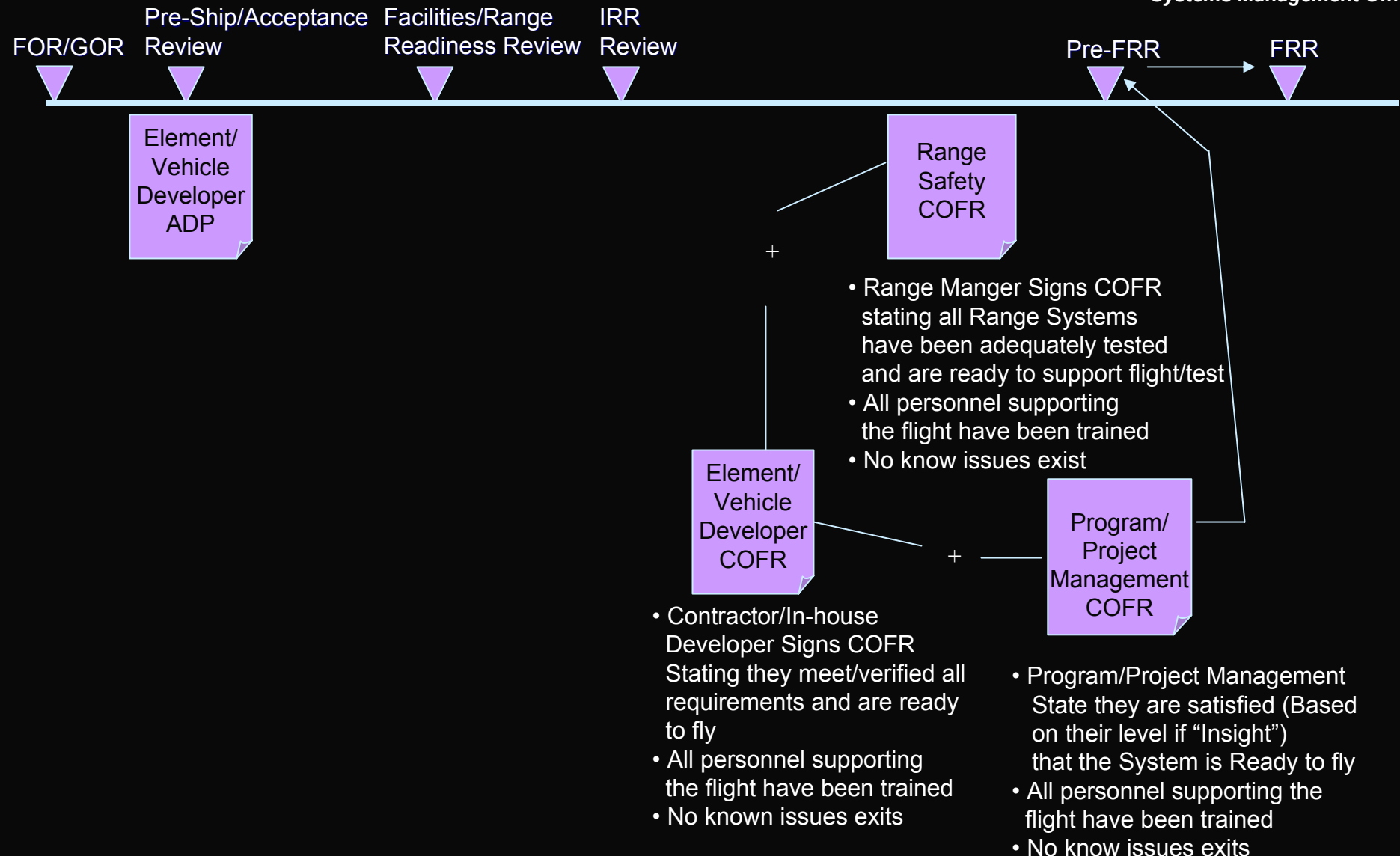
Top Level Flow/Steps



Program/Project Penetration



Systems Management Office



Continuous Risk Management

Risk is the probability that a project will experience undesirable consequences. - NPG 7120.5A

Continuous Risk Management = a systematic, ongoing process of identifying, analyzing and responding to project risk.

Risk = Likelihood (Probability) x Severity (Impact/Consequence)

Impact = the loss or effect on a project if the risk occurs

Probability = the likelihood the risk will occur

Timeframe = the period when you must take action to mitigate the risk

Possible Risk Responses: Accept, Watch, Mitigate, or Research

Program/Project Penetration



Systems Management Office

Risk Classification Chart:

Highest Probability of Occurrence	5					
Very High Probability of Occurrence	4					
High Probability of Occurrence	3					
Medium Probability of Occurrence	2					
Low Probability of Occurrence	1					
		1	2	3	4	5
		Minimal Impact	Minor Impact	Medium Impact	Major Impact	Unacceptable Impact

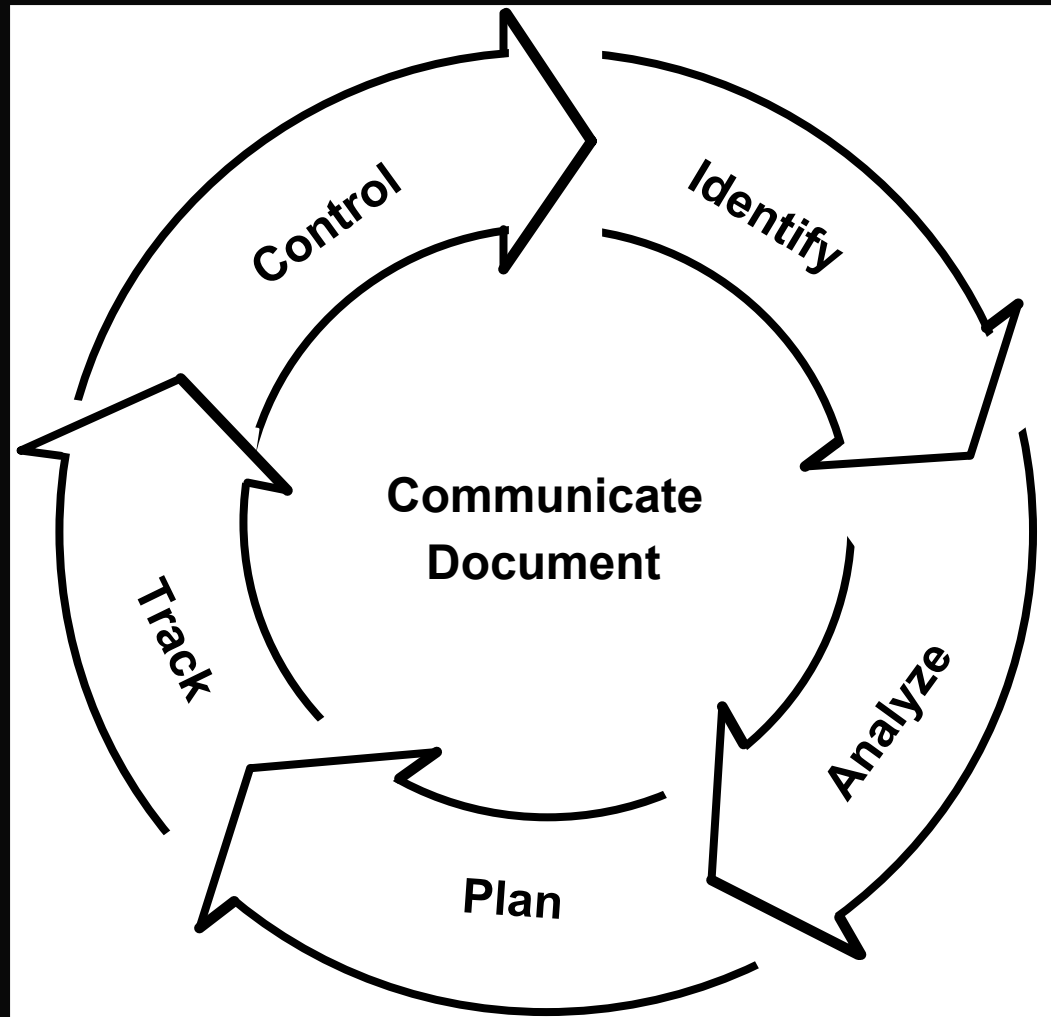
Items classified as Red are considered primary risk drivers. For these items, mitigation options will be developed. Red risks will be assessed for impact to budget reserves, and will be tracked to closure. Items classified as yellow and green are lower priority and will be watched and addressed as budget and schedule permits.

Program/Project Penetration



Systems Management Office

The Continuous Risk Management Process



There are six primary activities of the CRM process:

- Risk identification: continuous efforts to identify, acknowledge, and document risks as they are found. (The project manager is ultimately responsible for project risk. However, the PM may designate a risk manager or delegate risk management assistance to the Lead Systems Engineer. Initial risk identification usually begins with a brainstorming session with the project team, using the WBS as a tool to consider all aspects of the project components.)
- Risk Analysis: an evaluation of all identified risks to estimate the probability of occurrence, severity of impact, time-frame of expected occurrence or when mitigation actions are needed, classification into sets of related risks, and priority ranking.

The six primary activities of the CRM process (continued):

- Risk Planning: establishes actions, plans, and approaches for addressing risks and assigns responsibilities and schedules for completion. Metrics for determining the risk status are also defined during this step.
- Risk Tracking: an activity to identify, compile, and report risk attributes and metrics that determine whether or not risks are being mitigated effectively and risk mitigation plans are being performed correctly.
- Risk Controlling: an activity that utilizes the status and tracking information to make a decision about a risk or risk mitigation effort. A risk report may be accepted, closed, or watched, a mitigation action may be re-planned, or a contingency plan may be invoked.

Program/Project Penetration



Systems Management Office

The six primary activities of the CRM process (continued):

- Risk Communication and Documentation: provides information and feedback to the project on the risk activities, current risks, and emerging risks.

For more information or to sign up for the course on Continuous Risk Management contact:

Bill Loden / HEI

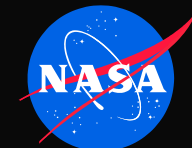
544-0877

Bill.J.Loden@msfc.nasa.gov

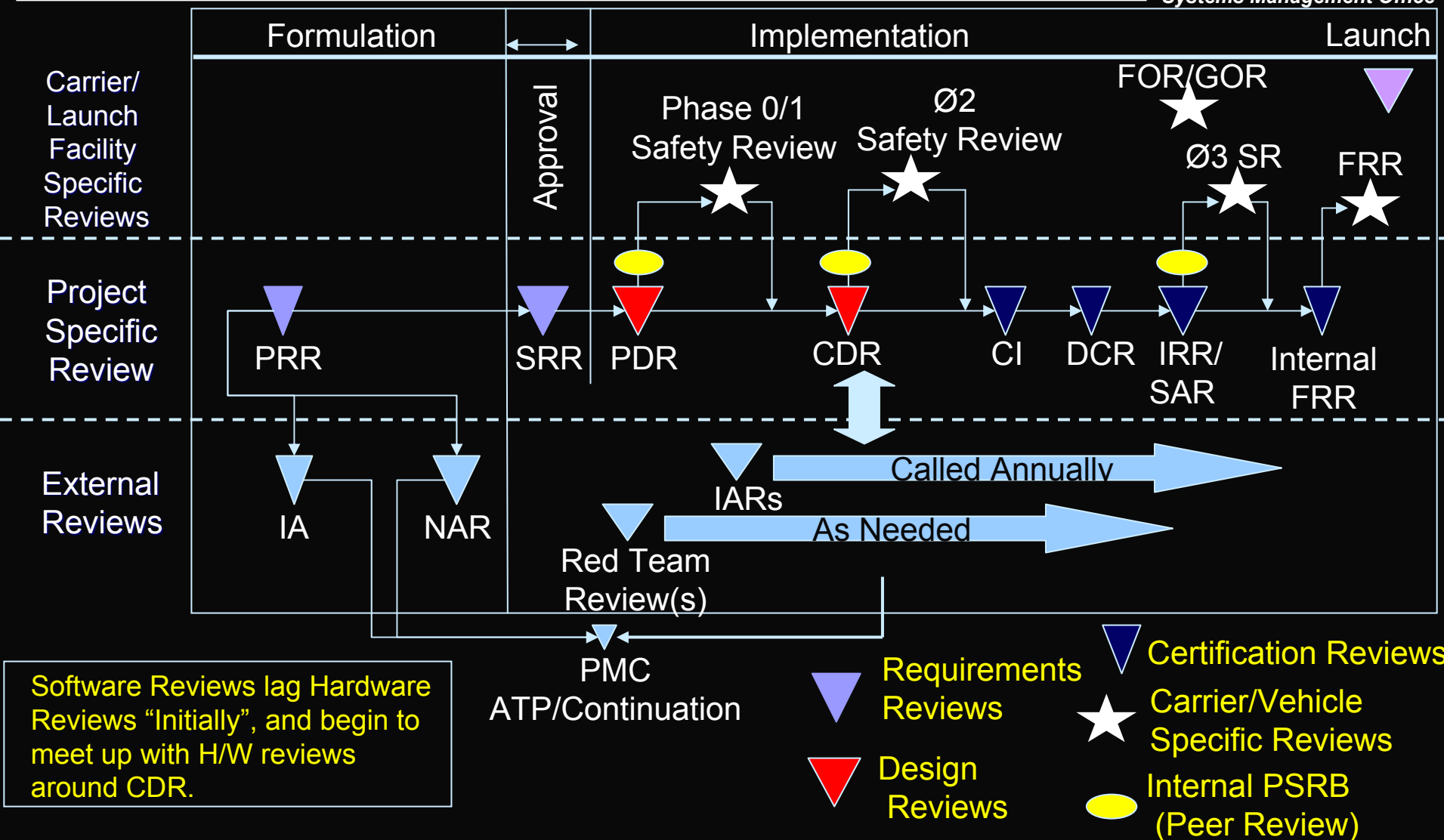


Reviews

Project Activities/Reviews



Systems Management Office



Project Requirements Review (PRR)



Systems Management Office

- **Project Requirements Review Purpose**

The **PRR** is held prior to Implementation ATP and is used to review and establish or update projects requirements and evaluate the management techniques, agreements, and procedures. Risk Planning is crucial throughout the life of the activity and is an integral part of this and subsequent reviews. It is also used to baseline Science Requirements (if any). Products supporting this review will be updated to support the System Requirements Review.

- **Reviewable Products**

- Program Plan (Level II Requirements)
- Project Plan
- Science Requirements (if any)
- Studies
- Agreements
- Review Plan (Requirements, Design, Certification)
- Concepts (Includes Ops)
- CWC/MSFC Manpower Requirements
- Systems Engineering Approach
- LCC Analysis
- Risk Planning

- **Participants**

Formulation Team, peers from outside (ED, S & MA, SMO, ...)

- **Outcome**

Assessment of Project Requirements and ability to meet them within an acceptable level of risk.

Independent Assessment (IA)



Systems Management Office

- **Independent Assessment Review Purpose**

The **IA** is held in support of the GPMC to validate an advanced concept being considered during formulation. It is usually considered only for high cost/visibility projects with a lengthy formulation activity or projects heavily dependent on new technology.

- **Reviewable Products**

- Project Background & Objectives/Requirements
- New Technology Required & Associated Risk
- Status of Technical Plans, Schedules & Cost Estimates
- Status of Management Plans
- Concepts Developed to date & Trade Studies

- **Participation**

IPAO usually Chairs review with SMO as Co-Chair, Project Team supports/presents.

- **Outcome**

Assessment of adequacy of project planning, independent validation of the advanced concepts, trades, suggestions for improvements. Recommendations are reviewed by the GPMC .

Non-Advocate Review (NAR)



Systems Management Office

- **Non-Advocate Review Purpose**

The **NAR** is held in support of the PMC to verify that the project is ready to proceed from the formulation sub-process to the implementation sub-process.

- **Reviewable Products**

- Project Background & Objectives
- Well defined Project Requirements
- Conceptual Design and Trade-Offs
- Project Plans (includes CM/DM)
- Risk Management Plan
- Schedule & Life Cycle Cost (Inc. Ops.)
- Safety Considerations
- Agreements with support organizations
- operation Concept Plans (Ground & Flight)
- Verification Approach

- **Participation**

SMO usually Chairs review with ED and others outside the Project as supporting team members, Project Team supports/presents

- **Outcome**

Assessment of adequacy of project definition and planning, suggestions for improvements. Recommendations are reviewed by the PMC and the "Implementation" Authority to Proceed decision is made.

System Requirements Review (SRR)



Systems Management Office

- **Systems Requirements Review Purpose**

The **SRR** confirms that the requirements and allocations contained in the System Specifications are sufficient to meet project objectives within an acceptable level of risk. It continues to evaluate the Systems Engineering and Risk Management approaches defined in the PRR.

- **Reviewable Products**

- Project Plan
- CM and DM Plans
- System Specifications (RIDable)
- Requirements vs Capability Matrix
- Quality Plans
- Systems Analysis & Trades
- Verification Approach
- Systems Engineering Process/Plan
- Logistics Plan
- Safety Plans
- Life Cycle Cost Analysis
- Risk Management Plan

- **Participants**

- Project Engineering Team, Peers outside project, Carrier personnel (ISS/STS), Launch site personnel, and Possible Red Team Members.

- **Outcome**

This review confirms that the requirements and their allocations contained in the Systems Specifications are sufficient to meet Project requirements/objectives.

Preliminary Design Review (PDR)



Systems Management Office

- **Preliminary Design Review Purpose**

The **PDR** is conducted when the basic design approach has been selected and the necessary documentation is available (usually when design maturity is at approx. 50% with 10% drawings available). This is a technical review of the basic design approach for configuration items to assure compliance with program (Level II) and project (Level III) requirements. It is intended to accomplish the following:

- Establish the ability of the design to meet the technical requirements
- Establish the compatibility of the interface relationships of specific end items with other interfacing end items
- Establish the producibility of the selected design
- Test and demonstration Planning, Safety, Risk Assessment, Reliability & Maintainability Assessment

- **RIDable Products**

- Requirements/Margin Matrix
- Preliminary Design Drawings
- Safety Analysis reports
- Preliminary FMEA/CIL, Preliminary Fault Tree
- Verification Plan
- Interface Control Documents
- Quality Plans
- Preliminary Operations Requirements (Launch and Flight)
- Logistics Plan
- Mass Properties Report
- Preliminary Ground Support Equip. Requirements
- Part I Contract End Item update
- Fracture Control Plan
- Risk Management Plan
- Safety Plans

- **Participants**

Project Engineering Team, Peers outside project, Carrier personnel (ISS/STS), Launch Site Personnel, and Possible Red Team Members

- **Outcome**

Assessment of readiness to proceed to CDR, baseline of key documents and inputs to Phase 1 safety reviews.

Critical Design Review (CDR)



Systems Management Office

• Critical Design Review Purpose

The **CDR** confirms that the project's system, subsystem, and component designs, derived from the preliminary design, is of sufficient detail to allow for orderly hardware/software manufacturing, integration, and testing, and represents acceptable risk. It is held when the design is approx.. 95% complete.

• RIDable Products

- Requirements/Margin Matrix
- Design Drawings
- Safety Analysis reports
- Updated FMEA/CIL
- Fault Tree Update
- Verification Plan
- Test Plan
- Fracture Control Plan
- Launch Site Support Requirements
- Interface Control Documents
- Logistics Plan
- Ground Support Equipment Design
- Part I Contract End Item update
- Mass Properties Report
- Risk Management Plan

• Participants

Project Engineering Team, Peers outside project, Carrier personnel (ISS/STS), Launch Site Personnel, and Possible Red Team Members.

• Outcome

Assessment to proceed into manufacturing, integration & testing, and completeness of all critical project documentation, plus inputs to the Phase 2 safety reviews.

Configuration Inspection (CI)



Systems Management Office

- **Configuration Inspection Review Purpose (Pre-ship/turnover type Review)**

The CI is a formal review that is used to establish the product baseline and to verify that the end items have been, and other like items can be, manufactured, tested, etc. to the released engineering documentation. This is accomplished by a comparison of the “as-built” configuration to the “as-designed” requirements.

- **Reviewable Products**

- CEI Specification
- Release records
- Test Requirements and Procedures
- Drawings and Eos
- Configuration Control Board Directive
- Waivers/Deviations
- Test log Book and Test Reports
- Certification of Quality
- Materials Certifications
- Vendor Certification of Flight Worthiness
- Safety Compliance Data
- Open Work List

- **Participation**

Management one level above the Project Manager (Minimum), Project Team, Peers from outside Project team, possible Red Team Members.

- **Outcome**

Approval to proceed, this is an incremental readiness verification covering key activities and leading to flight readiness.

Design Certification Review (DCR)



Systems Management Office

- **Design Certification Review Purpose (Pre-ship/turnover type Review)**

The **DCR** is conducted to evaluate the results and status of the verification planning, testing, and analysis and basically to certify the design met the requirements. These usually occur after CDR and prior to FRR; but depending on program structure, they may recur subsequent to other significant events such as completion of verification flights.

- **Reviewable Products**

- Contract End Item Specification
- Manufacturing Records
- Verification Plan and Requirements
- Drawings and EOs
- CDR RIDs
- Configuration Control Board Decisions
- Waivers/Deviations
- Test Log Book and Test Reports
- Certification of Quality
- Materials Certification
- Vendor Certification of Flight Worthiness
- Safety Compliance Data
- Hazard Analysis
- Risk Assessment
- Open Work List

- **Participation**

Project Team, Peers from outside Project, possible Red Team Members (Depending on Project criticality this review may be Co-Chaired by the Directorate Director and ED Director).

- **Outcome**

Approval to proceed, this is an incremental readiness verification covering key activities and leading to flight readiness.

Acceptance Review (AR)



Systems Management Office

- **Acceptance Review Purpose (Pre-ship/turnover type Review)**

The **AR** is the final review conducted for product delivery and NASA acceptance. It assures that the design and performance meet requirements. It encompasses not only flight hardware and ground support equipment but also any deliverable test article, spares, special test equipment, support software, etc. All documentation, including the acceptance data package (ADP), should be examined for compliance with requirements, and all open/deferred work identified. At the conclusion the responsibility is transferred from the Contractor to NASA.

- **Reviewable Products**

- ADP which includes
 - As-built configuration assembly & installation drawings
 - Final Mass Properties Report including wt/balance sheet
 - Final Safety Compliance Data Package (ISS/STS payloads)
 - Complete Hazard Report with supporting data
 - As-built certification data on safety critical structures
 - Final Verification Analysis and Test Reports
 - Vendor Certification of Flight Worthiness
 - Final Requirements Document/Specifications, Limited Life Items List,...
- Users Manuals
- Open Items/Work List
- Waivers/Deviation/CCBDs
- Material Usage Agreement
- All alerts
- Final Risk Assessment
- Interface schematic drawings

- **Participants**

Project Team, Peers from outside Project, possible Red Team Members (Depending on Project criticality this review may be Co-Chaired by the Directorate Director and ED Director).

- **Outcome**

Approval to proceed, this is an incremental readiness verification covering key activities and leading to flight readiness.

Flight Readiness Review (FRR)



Systems Management Office

• Flight Readiness Review Purpose

The **FRR** is held to certify that the hardware/software is ready for flight, that all open work is planned and understood, that all constraints to launch are identified and that all flight operations personnel, documentation and critical facilities are ready to support operations.

• Reviewable Products

- Update to certification status from the AR
- Vendor Certification of Flight Readiness
- MSFC Certification of Flight Readiness
- Resolution of all Open Work
- Outstanding Risks & Mitigation Plans
- Operations Facilities/Personnel Readiness

• Participants

Project Team, Peers from outside Project, possible Red Team Members (The PCA, Program Plan, and the Project Plan will identify the Board Chairperson) For all projects, the highlights of the review will be presented to the Center Director).

• Outcome

Certification that the hw/sw and operations personnel, procedures and facilities are ready to support launch and operations of the Project.

Independent Annual Review (IAR)



Systems Management Office

- **Independent Annual Review Purpose**

The **IAR** is held in support of the PMC to verify that the project is proceeding “as planned”.

- **Reviewable Products**

- Status of Progress/Milestone Achievements vs. Original Baseline
- Status of Life Cycle Cost current requirements vs. Original Baseline
- Overview of Project (Including Project Plans)
- Status of changes since last IAR or NAR
- Status of Technical Progress, Risk Remaining & Mitigation Plans

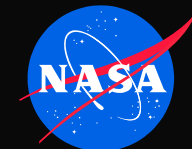
- **Participation**

SMO usually Chairs review with Engineering Directorate and others outside the Project as supporting team members, Project Team supports/presents

- **Outcome**

Assessment of status of project technically, schedule adequacy, Life Cycle Cost, and remaining risk. Recommendations are reviewed by the PMC.

Responsibility for IAR



Systems Management Office

The Project Manager has responsibility to assess need for an IAR and should document that decision within the Project Plan

Project Managed By	GPMC Location	IAR Lead Responsibility
MSFC	MSFC	MSFC SMO
MSFC	Other Center	MSFC SMO
Other Center	MSFC	Other Center SMO
Any Center	NASA HQ	IPAO

• Red Team Review Purpose

This review is held in support of the Directorate Chief Engineer. The purpose of a Red Team Review is to provide an objective, non-advocate review of the plans and processes in place that ensure Mission Success and Safety are being considered and implemented. It is not a design review nor a program management process review except as necessary for the stated purpose.

• Reviewable Products

- Overview of the program/project
- Program/project plans
- Previous peer review results/actions taken
- The re-furbishment and maintenance performed or planned
- Requirements flow down of Mission Success and Safety criteria
- Component/system/element analysis and validation processes
- Process/plans implemented/planned to prevent each potential failure
- Identification of any reuse hardware or software and any modifications made
- Identification of all single point failures and justification for lack of redundancy
- Definition of all items that could cause a failure to achieve these criteria and the logic used to establish these criteria
- Completed end-to-end systems and analysis, tests and simulation results and future end-to-end planned activities
- Risk Analysis and Processes
- Definition of Mission Success and Safety Criteria
- Current and planned contingency plans
- Hazard Analysis and Processes
- Configuration Management Plan
- Design review(s) plan(s)

• Participation

The Team is comprised of Senior Personnel from outside the Project Team, Project Team supports/presents.

• Outcome

Assessment of the project with recommendations reported to the Chief Engineer

Project Activities/Reviews



Systems Management Office

- **Summary**

- **MSFC's Review Process addresses the NASA Integration Action Team "EX-1 Reviews" Findings/Recommendations:**
- **The Review Process is defined in the Project Management & Systems Engineering Handbook**
- **When fully implemented Project Risk is Minimized**
- **Peer Reviews should be viewed as a resource to Projects**
 - Peer Reviews include:**
 - **Blue Team (Proposal Development)**
 - **SRR, PDR, CDR, AR, ... (Peers invited to participate/evaluate work as review team members, Peers also support as Pre-board and Board members)**
 - **Internal and External Safety Reviews**
 - **Red Team Reviews/External Reviews (IA, NAR, IAR...)**

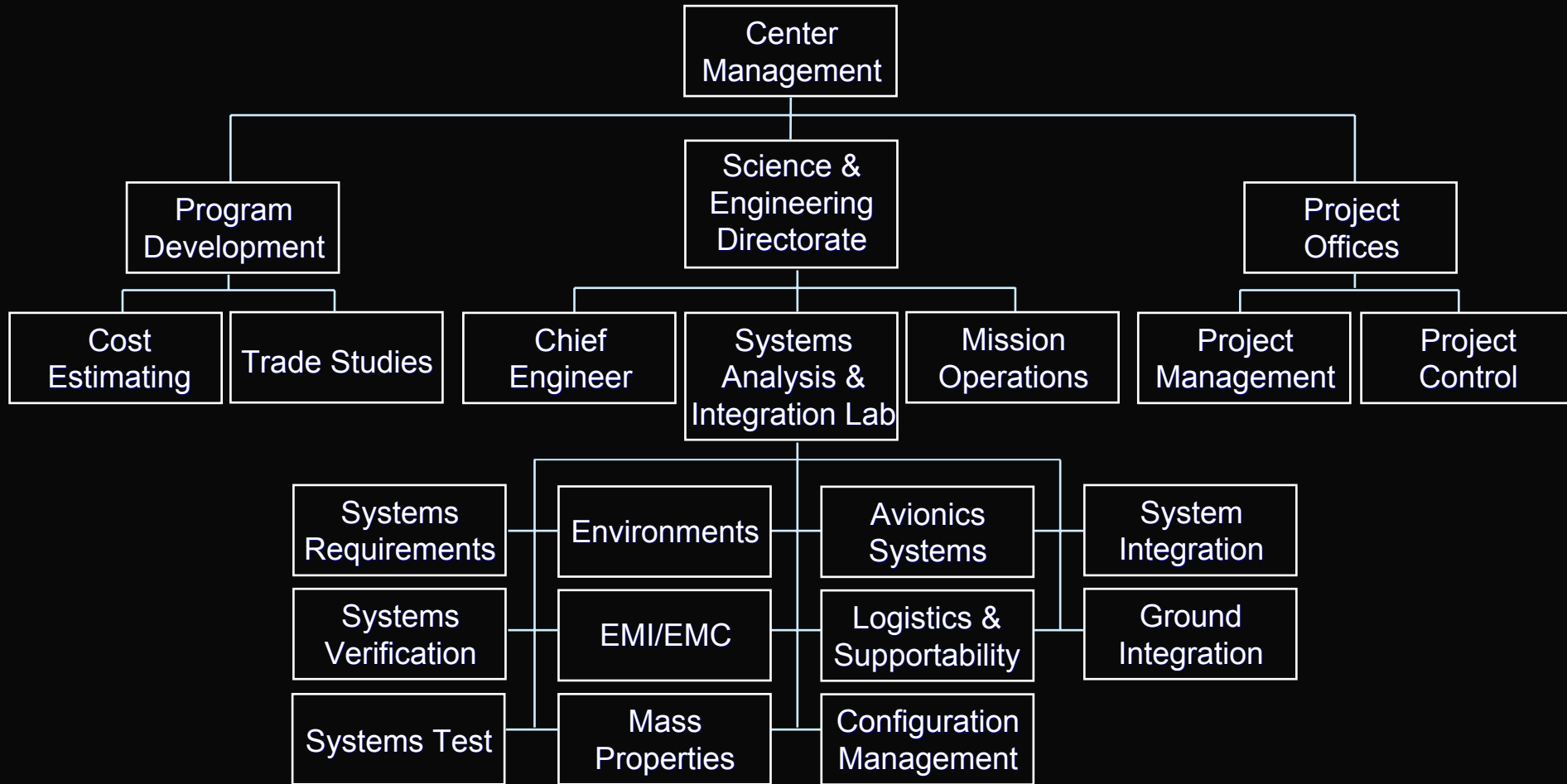


Project Organization Roles & Responsibilities

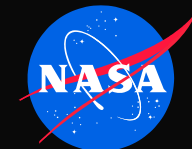
Reallocated MSFC SE Functions (Pre-Reorganization)



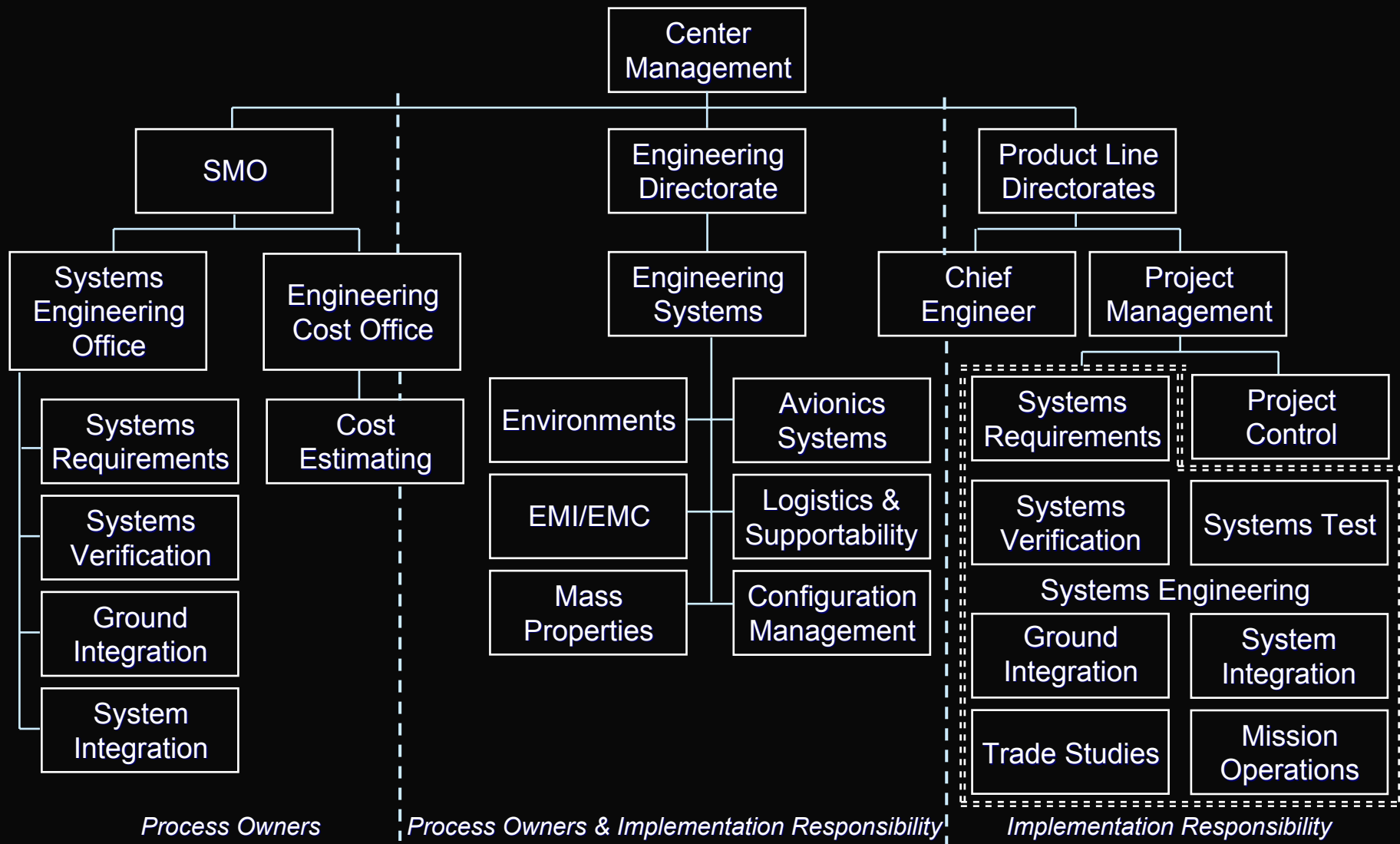
Systems Management Office



Reallocated MSFC SE Functions (Post-Reorganization)



Systems Management Office



Project Manager's Role



Systems Management Office

- The Project Manager (PM) is responsible for all aspects of the project and is accountable to the Directorate Head
 - Cost
 - Schedule
 - Technical Performance
 - Administrative
 - Risk Management
- PM has a direct interface with the Contractor team PM and with the Customer (fund source, science/technology sponsor, Program Manager)
- PM also:
 - Ensures that the project meets all NPG 7120.5 requirements
 - Maintains a project check list
(customized for the project from the Mars Climate Orbiter Report ftp://ftp.hq.nasa.gov/pub/pao/reports/2000/MCO_MIB_Report.pdf)
 - Schedules regular programmatic and technical reviews to assess project status

Directorate Chief Engineer's Role



Systems Management Office

- The Chief Engineer is the principal technical advisor to the Directorate/Office
 - Responsible for overseeing technical aspects of all projects within the Directorate/Office
 - Mentors and advises Project LSEs and LSSEs
 - Provides lessons learned and advises Directorate Heads/Program Managers on technical matters
 - Assures that technical skill mixes within the Directorate/Office are appropriate
 - Leads in organizing and conducting Red Team Reviews

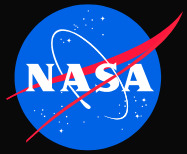
Lead Systems Engineer's Role



Systems Management Office

- The Lead Systems Engineer is accountable to the PM to ensure that the project system requirements are met.
- The Lead Systems Engineer leads the following activities:
 - Hardware and software requirements and verification development
 - Flow down of requirements to subsystem level
 - Allocation of technical resources and error budgets to subsystem levels and monitoring progress through Technical Performance Measurement parameter reporting
 - System modeling and analysis for the purpose of validating system requirements
 - Performance of system level trade studies leading to the best approach to meet the requirements
 - Execution of system level risk management activities
 - Design Review coordination
 - Hardware/software integration
 - Operations planning/concept development
 - Development of the Systems Engineering Management Plan

Lead Subsystems Engineer's Role



Systems Management Office

- The Lead Subsystems Engineer is accountable to the PM to ensure that the technical performance of the subsystem element is acceptable.
- The Lead Subsystem Engineer leads the following activities:
 - Assures that subsystem level and component level requirements, flowed down from the system level requirements, are met
 - Assures that subsystem risk management activities are properly executed
 - Assesses engineering discipline interfaces as required
 - Works with line management to staff subsystem tasks on the project

Systems Engineering Management Plan



Systems Management Office

- Describes overall technical management approach
- Typically developed as stand alone product for large projects and integrated into Project Plan for small projects.
- Developed concurrently with Project Plan
- The Systems Engineering Management Plan (SEMP)
Includes:
 - Systems Engineering organization and responsibilities
 - Systems analysis and design approach
 - Manufacturing and acquisition plan
 - Systems integration approach
 - Schedule including technical reviews
 - Engineering documentation

Program / Project Plan



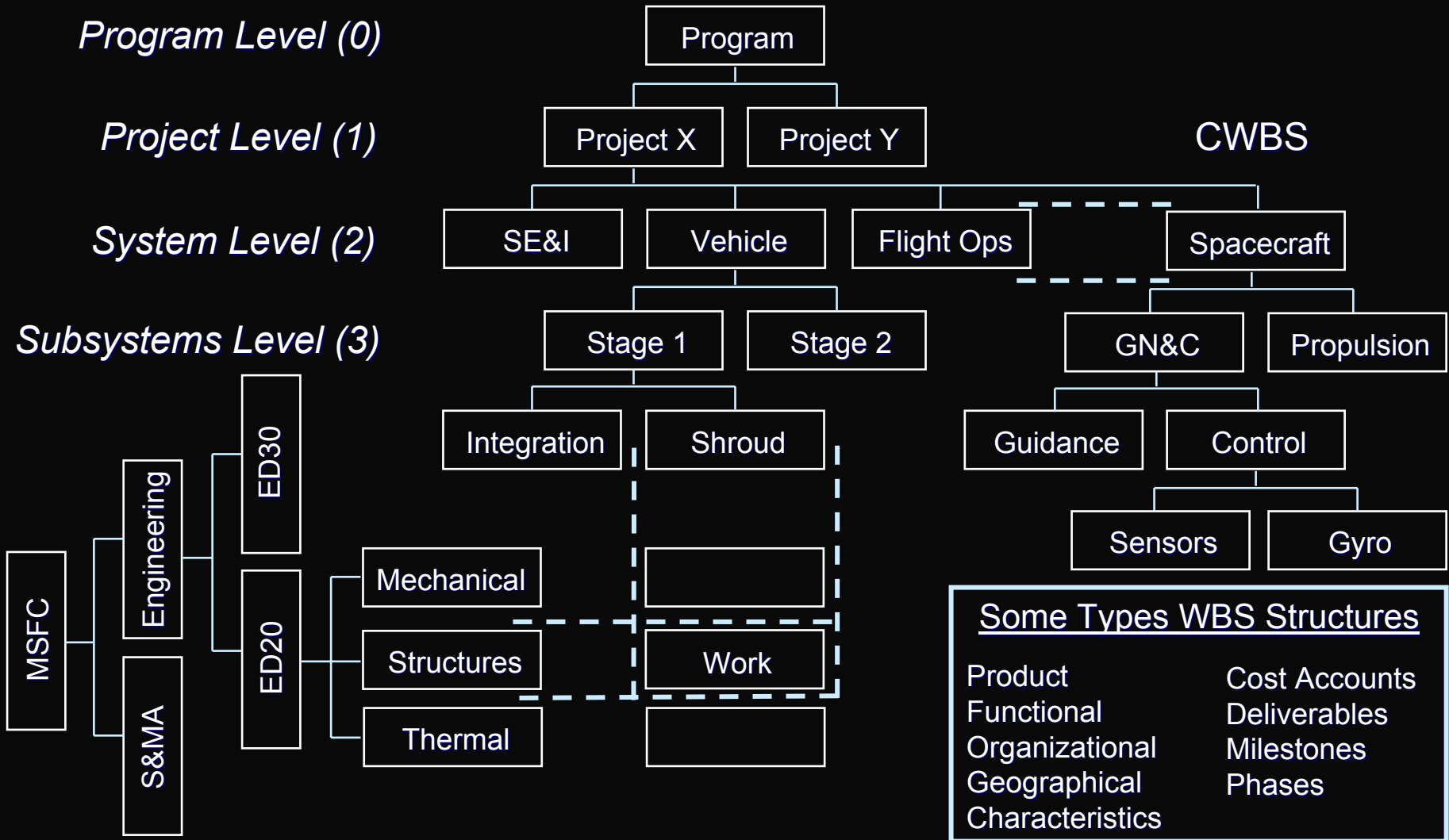
Systems Management Office

- The Program/Project Plan is the document where all up-front planning for the program/project comes together.
- The Program/Project Plan is prepared in the Formulation stage and this plan's approval per MPG 7120.1 signifies the beginning of the Implementation Phase.
- The PCA, Operations Concept, Program Plan (for projects) all feed the Program/Project Plan. The planning required to generate the Program/Project Plan will serve as input to other required plans: Safety Plan, Quality Plan, Configuration Management Plan, Data Management Plan, Risk Management Plan, Systems Engineering Management Plan, etc.
- A set of requirements that define “success” for the program or project is the foundation of the program or project plan.
- All plans require a minimum concurrence from SMO, Procurement, and S&MA prior to approval.

Work Breakdown Structure (WBS)



Systems Management Office



Work Breakdown Structure (WBS)



Systems Management Office

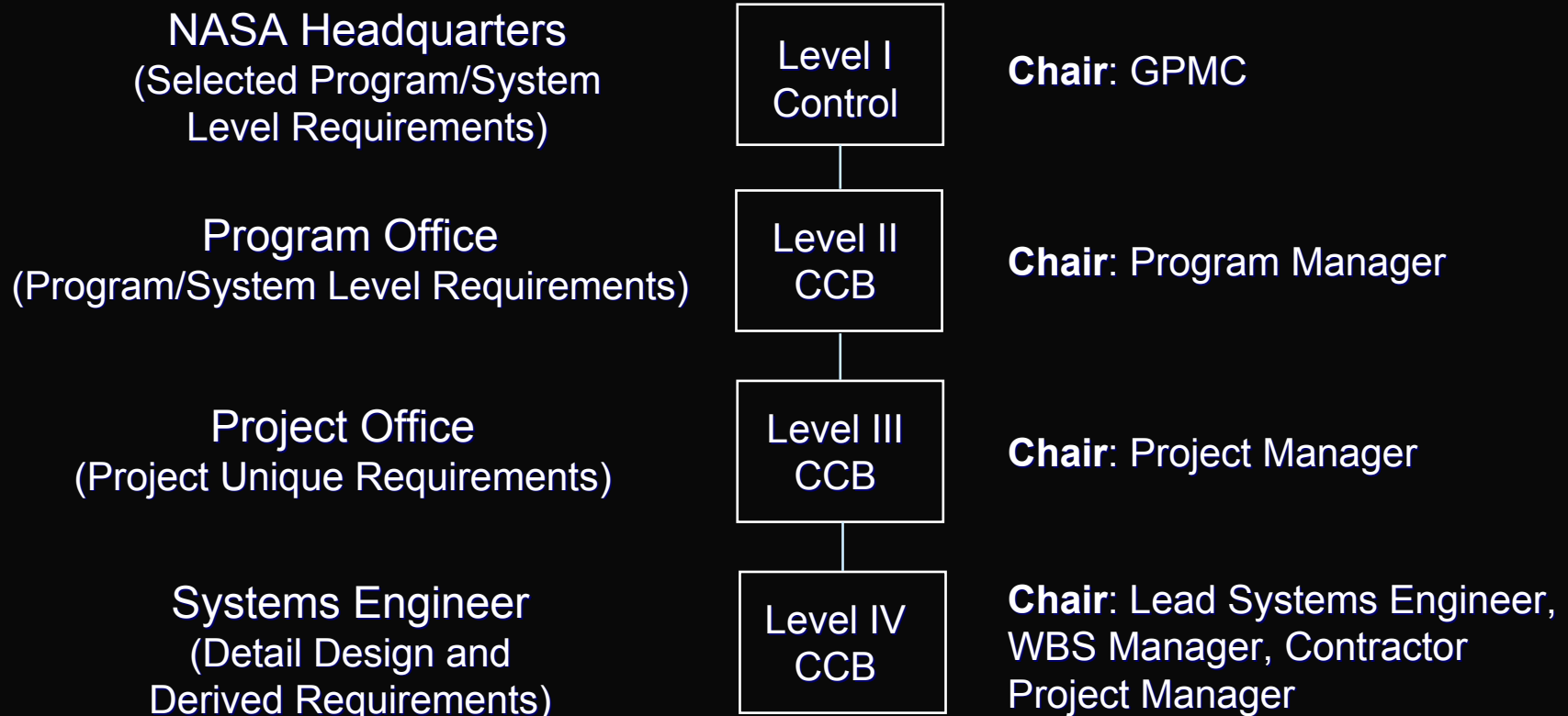
- **What makes up a good WBS?**
 - Easily understood and logical work descriptions
 - Work elements have clear start and end points with measurable milestones
 - One that includes all work for project, not just product breakdown
 - Aligns management and product, preferably using product oriented WBS
- **What are benefits of a good WBS?**
 - Work is easily controlled
 - Relationship between parts, tasks, and end-product are clear
 - Eases tracking engineering resources, estimates, and performance
 - Provides framework for reporting
 - Assists in risk identification, interface management, trade studies, and configuration management
- **Refer MIL-HDBK-881 and NASA WBS handbook (http://appl.nasa.gov/tools/tools_wbs.htm) for additional information**

- Configuration Management is a formal and disciplined systems approach for the establishment and control of the planning, requirements, and configuration for hardware/software developed for NASA.
- The 4 elements of Configuration Management:
 - Identification - selection of items to be controlled
 - Control - establishing baseline and controlling changes
 - Accounting - recording and reporting status of baselines, deviations/waivers, and hardware/software configurations
 - Verification - comparison of as-built to as-designed (PCA)

Configuration Change Board Hierarchy



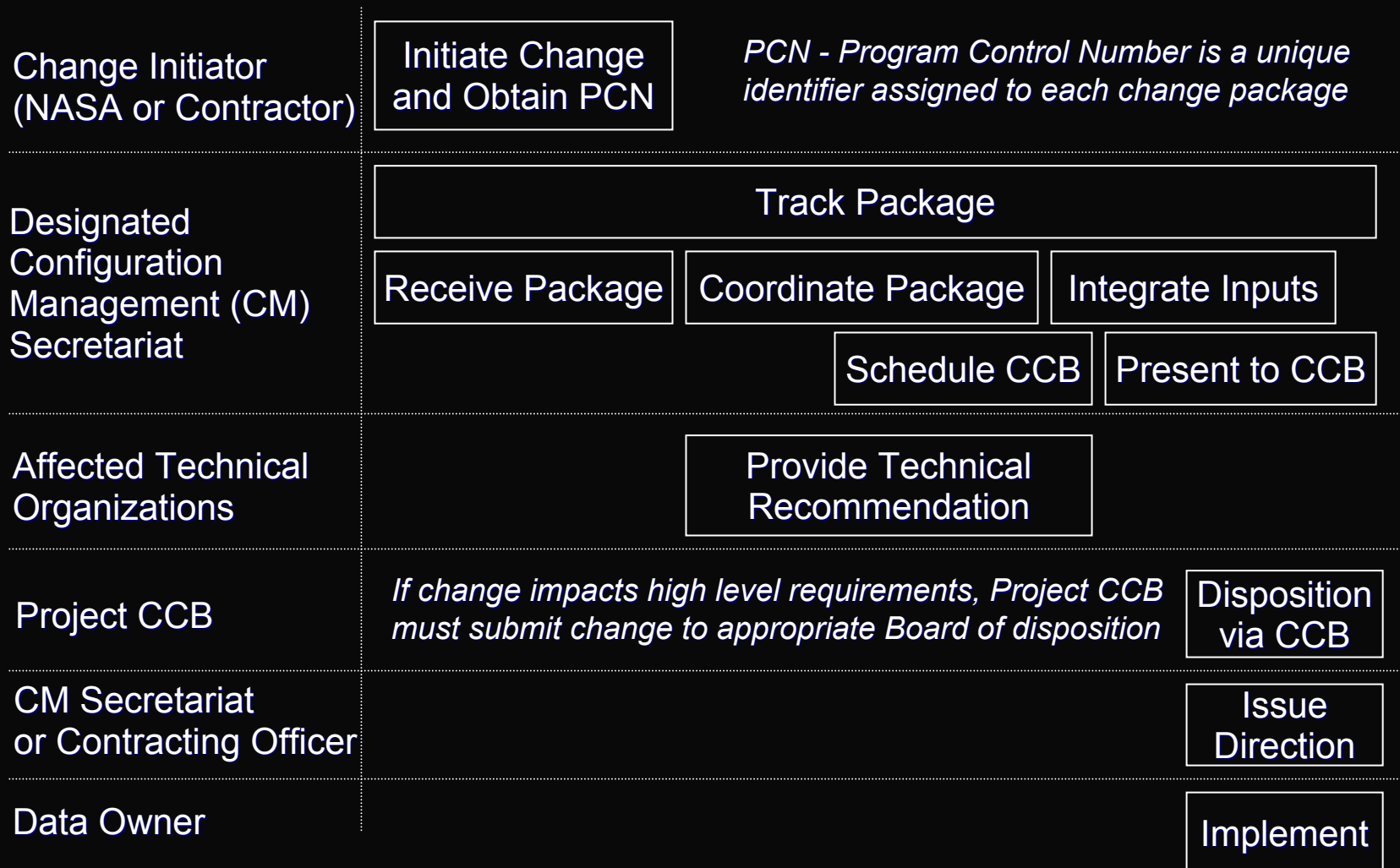
Systems Management Office



CM Change Process Flow



Systems Management Office



- The Project Manager defines the Data Requirements during Formulation in accordance with MWI 7120.2 and appoints the Project unique Data Manager (DM).
- The DM develops the Data Management Plan (DMP), in accordance with MWI 7120.5 and Project policies, that describes implementation of the data management requirements.
- The OPR for the required data submits data in accordance with the DMP and MWI 7120.4 (or the SOW for contractors).
- Data Export Control should be performed in accordance with MPG 2190.1.

- Selection of contract type will have a major impact on Program/Project management requirements
 - Systems Engineers may be involved in oversight of technical tasks
 - Systems Engineers may have input to the contractor's performance evaluation
 - Systems Engineers will be required to serve on SEBs
- The (2) broad categories of contract types are Fixed Price and Cost-Reimbursement
 - Many sub-types exist, each have advantages and disadvantages in meeting a specific need
 - Things to consider when selecting the contract type:
 - Price competition and price analysis
 - Type, complexity, and urgency of the requirements
 - Period of performance or length of production run
 - Contractor's technical capability and financial responsibility
 - Adequacy of Contractor's accounting system
 - Concurrent contracts
 - Extent and nature of proposed sub-contracting and acquisition history

Fixed Price Contracts



Systems Management Office

Type	Description	Application
Firm fixed-price	Provides for a price that is not subject to any adjustment due to contractor's costs	Acquiring commercial items, supplies or services on the basis of a specification
Firm fixed-price contracts with economic price adjustment	Stated contract price is adjustable based upon price changes and cost of labor and materials	When there is doubt concerning the stability of the market or labor conditions during the performance period
Fixed-price incentive contract (firm contract)	Provides for adjustment of profit and final contract price per a formula relating final negotiated total cost to total target cost	When an initial firm target cost, target profit, and profit adjustment formula can be negotiated
Fixed-price contracts with prospective price redetermination	Provides for an initial period of deliverables and performance and a redetermination of price for future periods of performance	Acquisition of quantity production or services for which a fair and reasonable price can be renegotiated for an initial period but not subsequent periods
Fixed-ceiling –price contracts with retroactive price determination	Provides for a fixed ceiling price and retroactive price redetermination after contract completion	Appropriate for research and development contracts estimated at \$100,00 or less
Firm-fixed price, level-of-effort term contracts	Contractor is paid a fixed dollar amount for a specified level of effort on a general statement of work over a stated period of time	Suitable for investigation or study in a specific research and development area.

Cost-Reimbursement Contracts



Systems Management Office

Type	Description	Application
Cost contracts	A cost reimbursement contract in which the contractor receives no fee	Research and development work especially with non-profit organizations and for facility contracts
Cost-sharing contracts (includes cooperative agreements)	A cost reimbursement contract in which the contractor receives no fee and is reimbursed only for an agreed upon portion of the allowable costs	Used when the contractor agrees to absorb a portion of the cost
Cost-plus-incentive-fee contracts	The initially negotiated fee is adjusted later based on a formula relating total allowable costs to total target costs	Appropriate for services or development and test programs
Cost-plus -award-fee contracts	Provides for a fee consisting of a fixed amount and a separate award amount based on contractor performance	Suitable when it is neither feasible nor effective to devise predetermined objective incentive targets for cost, schedule or technical performance
Cost-plus-fixed -fee contracts	Provides for payment of a negotiated fixed fee	Performance of research or preliminary study; level of effort is unknown.



- Contractor performance metrics will be an element of every NASA contract
 - Typical evaluation criteria include cost, schedule, and technical performance
 - Evaluation requirements vary depending on contract type
- References
 - NASA FAR and FAR Supplement Part 16
(<http://inside.msfc.nasa.gov/index.html/pr.html>)
 - NPG 9501.2C NASA Contractor Financial Management Reports
 - NPG 5800 ID Grant and Cooperative Agreement Handbook
 - MWI 5116.1 Evaluation of Contractor Performance Under Contracts with Award Fee Provisions

Program Operating Plan (POP)



Systems Management Office

- Program Operating Plan (POP) must be submitted twice per year by the Program Office
 - Includes funding, schedule, and personnel requirements
 - Establishes the Program Manager's contract with Center Management for resource commitment
 - Sets the criteria by which the Program will be measured
- POP process begins with a call from Headquarters
 - Centers provide resource requirements for the next (5) years starting (1) year from the beginning of the next fiscal year (20 months away)
- After analysis of the Centers inputs, Headquarters issues the next call in May with guidelines for Centers to update the original POP

Program Operating Plan (POP)



Systems Management Office

- Review Process
 - Program Manager, Center Management, and Headquarters (typically the Enterprise Associate Administrator) each conduct a review of POP submittal
- The POP process establishes subsequent budget marks, personnel support, and schedule for each Program element
 - Results form the basis for the Agency's budget submittal to the Office of Management and Budget (OMB)
 - Following final Center Director and Headquarter approval, the POP becomes the official Program resource plan
 - The resource plan is the basis for reporting actual budget expenditures and release of funding from NASA Headquarters

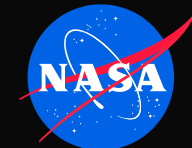
Annual Workforce Review



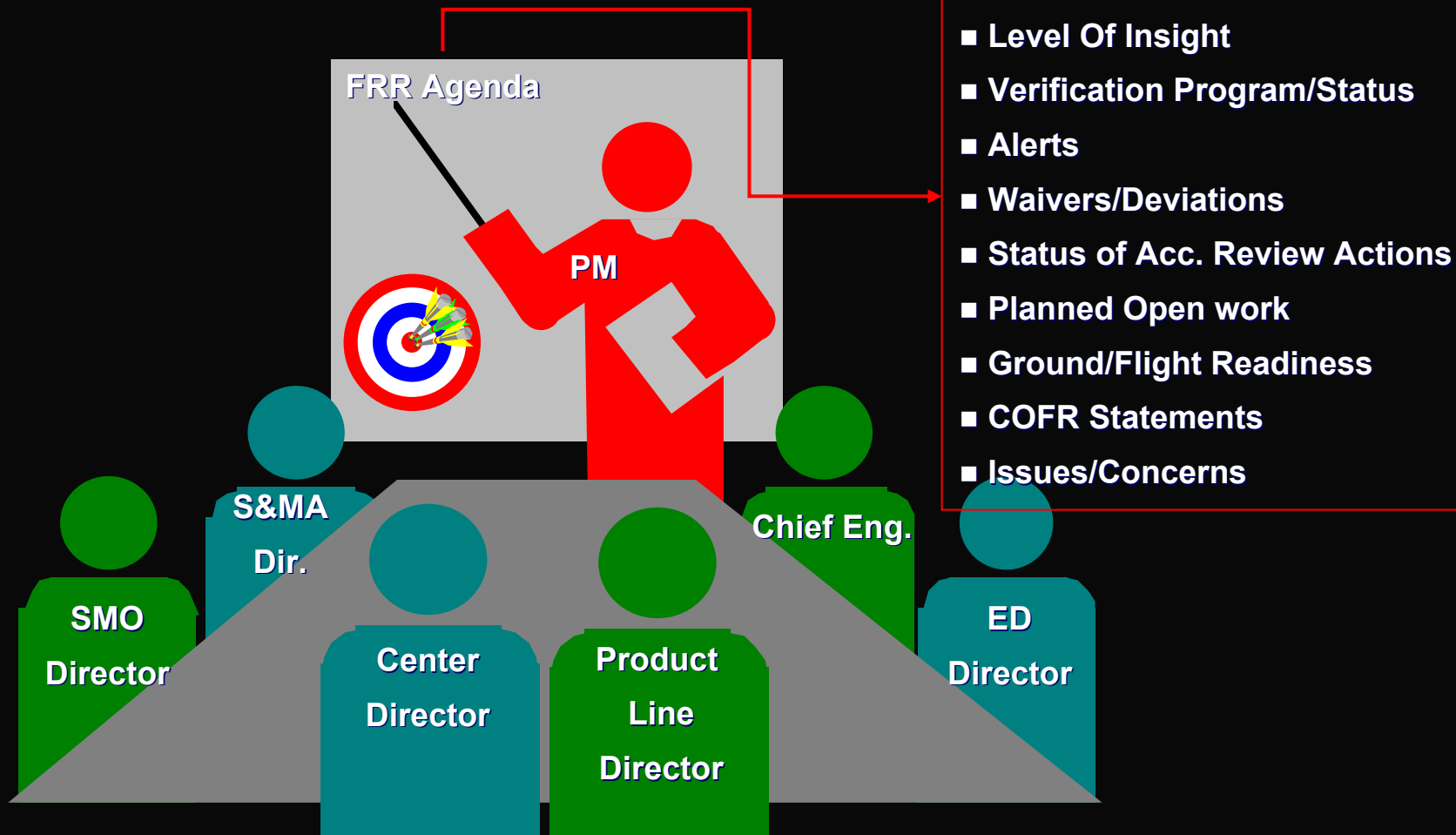
Systems Management Office

- Prior to the fiscal year, each Program and Project will negotiate resource requirements for that fiscal year with the appropriate Center organizations providing the service.
- Tasks will be developed specifically defining performance, funding, and schedule requirements.
- Resources required to perform the tasks will be agreed to through the Resource Planning process defined in MPG 1230.1 (Draft).
- The 5 year Strategic Planning Agreement (SPA) and 1 year Collaborative Work Commitment (CWC) agreement are presented to Center Management, together with program office resource requirements, in the Annual Workforce Review.
- The review will include a description of the work to be performed, justification for the manpower levels requested, and any other factors which have a bearing on the requested resources.

Flight Readiness Review



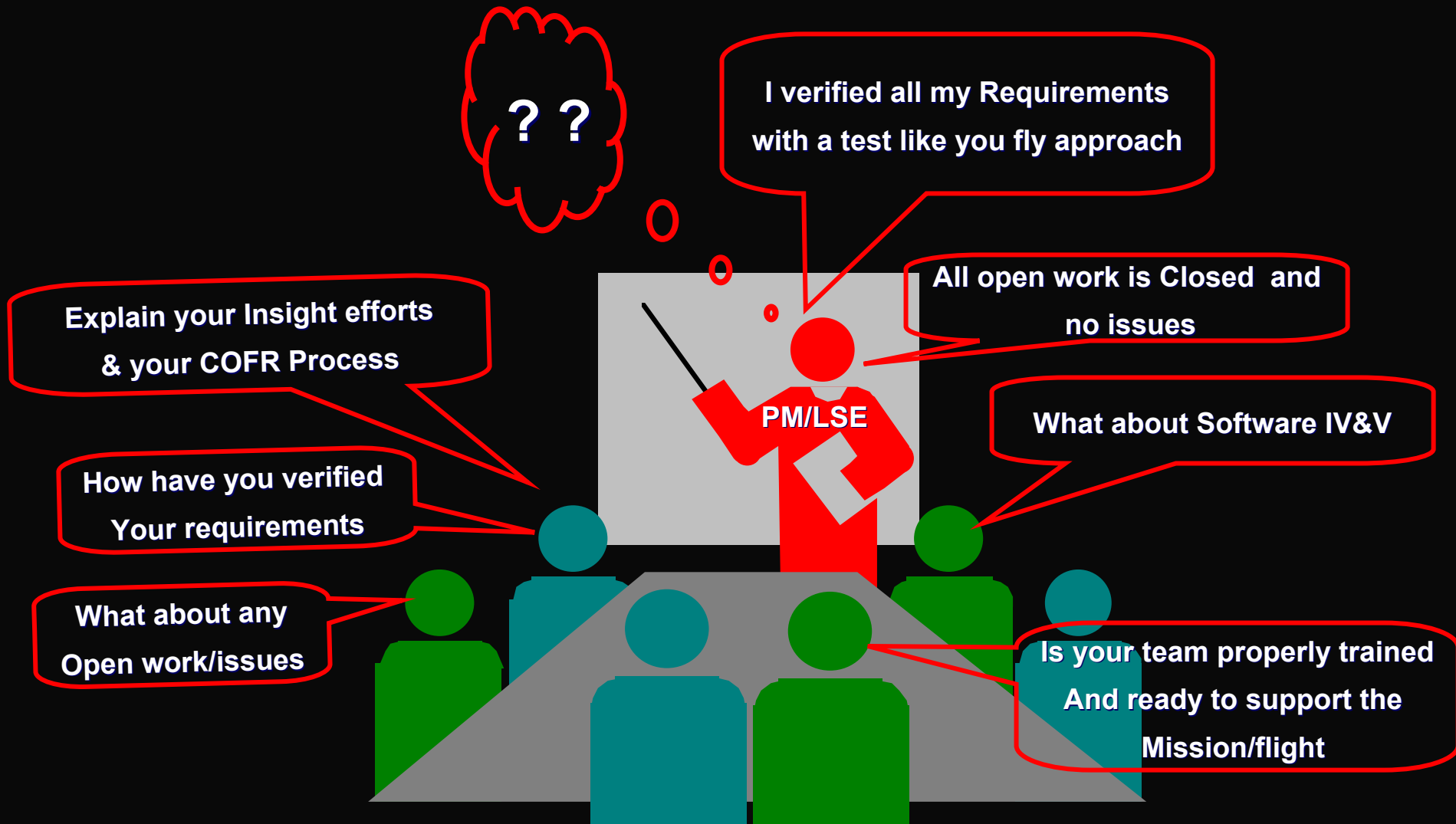
Systems Management Office



Flight Readiness Review



Systems Management Office



Flight Readiness Review Planning



Systems Management Office

•Flight Readiness Review (FRR) Purpose

The **FRR** is held to certify that the hardware/software is ready for flight, that all open work is planned & understood, that all constraints to launch are identified and that all flight operations personnel, documentation and critical facilities are ready to support operations.

• Project Managers/Project Engineer/Project Teams Responsibilities

To do the “Proper” Formulation Planning and Implement the Project consistent with the Plan so when FRR occurs you have a “Solid” story conveyed through your presentation

(How will the COFR statement read? **Plan early or pay later!!!**)

- Risk Planning/Mitigation...Proper Level of Insight
- Reviews (Internal/External)
- Configuration control/audits
- Analytical/Physical Integration...Requirements Verification/Validation
- ...

Flight Readiness Review



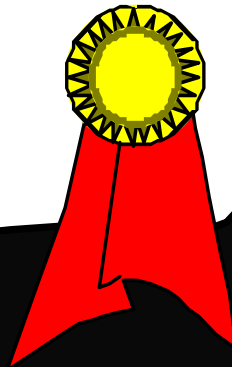
Systems Management Office

Projects

Certification of Flight Readiness

The project has met all the Program and Project guidelines And Requirements and is ready for flight and mission operations, pending closure of identified open Work.

Project Manager



Partners

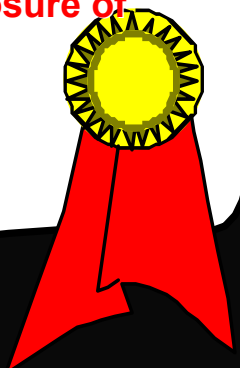
(PED/Vehicle Dev.)

Certification of Flight Readiness

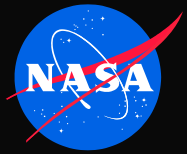
Based on Project Requirements (HW/SW performance, planned Mission environment, and planned operations), the team is satisfied that the H/W & S/W is capable and ready to meet the mission objectives, pending closure of identified open work .

Manager

Engineering



Flight Readiness Review Results



Systems Management Office

Great Job!

**I believe the Board's ready
to Sign the Approval sheet...
You still have a few actions
To work...so keep us
Informed...and good luck!**

**FRR Boards Approval/
Signature**

PM

**S&MA
Dir.**

**SMO
Director**

**Center
Director**

**Product
Line
Director**

Chief Eng.

**ED
Director**



MSFC

Systems Management Office

SMO Mission Statement



Systems Management Office

“The SMO provides support and independent evaluations of projects and programs for compliance with and implementation of Project/Program NPG 7120.5A, NASA Program and Project Management Processes and Requirements and, as appropriate, the Marshall Quality Manual. We determine consistency across product lines for Center systems engineering functions related to space systems program/projects, including requirements development and flow-down, program verification, and cost projections. We provide leadership, consultation services, and technical expertise on systems engineering processes and provide support in forecasting costs to advanced program/project planning initiatives.”

SMO Charter

SMO Charter Responsibilities



Systems Management Office

1. Reviews and evaluates Center programs/projects and provides project management guidance in the formulation stage.
2. Conducts Independent Assessments, Non-Advocate Reviews, Independent Annual Reviews, and participates in program/project reviews.
3. Provides to the Center Director an independent evaluation of the progress of programs/projects toward meeting technical requirements within cost and schedule commitments.
4. Serves as a member to the MSFC Program/Project Management Council.
5. Supports the Agency Chief Engineer and Agency Independent Program Assessment Office by participating in reviews of other NASA Center's projects and providing expert cost, schedule and economic analysis services.

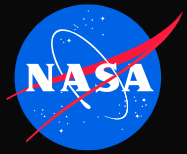
SMO Charter Responsibilities



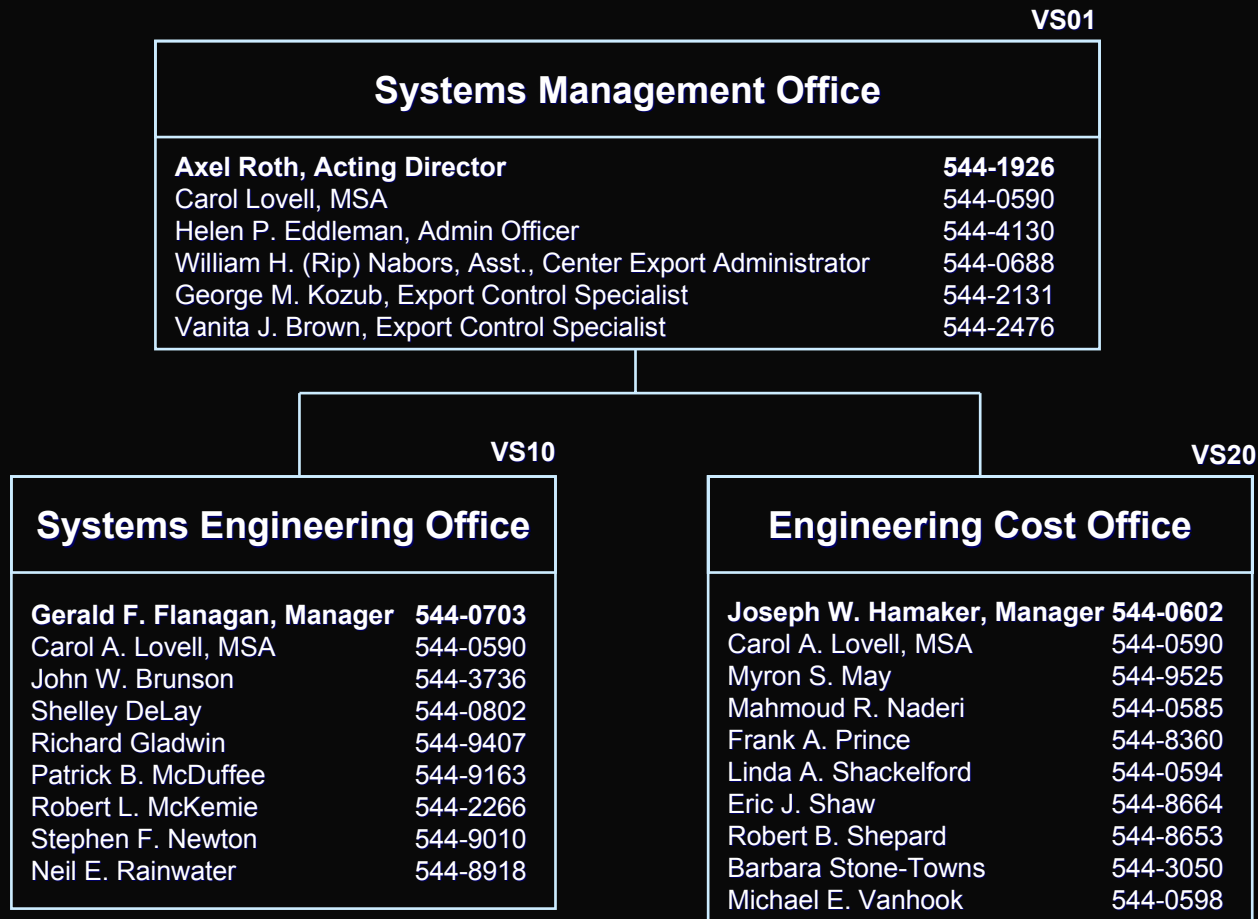
Systems Management Office

6. Directs the development of standard processes, tools, and guidelines for the systems engineering function.
7. Defines and coordinates Centerwide training/mentoring systems engineering practices and processes.
8. Provides the Secretariat role for all MSFC PMCs.
9. Prepares independent engineering cost, schedule and economic analysis for MSFC programs/projects in the formulation stage.
10. Develops and maintains an Agency database of historical cost, schedule and technical data from completed and ongoing programs/projects. Develops NASA-wide cost and schedule estimating techniques. Provides supporting software, documentation, training and regular updates.
11. Leads the Center's Export Control function.

Systems Management Office (SMO)



Systems Management Office



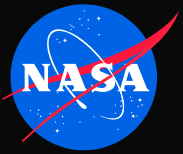


Appendices

- **Project Management White Paper**
- **Cost Control White Paper**
- **Earned Value White Paper**
- **Project Management Check List**



Acronym List



Acronyms

Systems Management Office

AC	Assembly Complete
ADP	Acceptance Data Package
AO	Announcement of Opportunity
APMAT	Alternative Propulsion Module Assessment Team
AR	Acceptance Review
ATP	Authority to Proceed
B/L	Baseline
CAN	Cooperative Agreement Notice
CCB	Configuration Control Board
CCBD	Configuration Control Board Directive
CDR	Critical Design Review
CEI	Contract End Item
CI	Configuration Inspection Configuration Item
CIL	Critical Items List
CM	Configuration Management
COFR	Certificate of Flight Readiness
CWC	Collaborative Work Commitment
DCE	Directorate Chief Engineer
DCR	Design Certification Review
DDT&E	Design, Development, Test & Evaluation



Acronyms

Systems Management Office

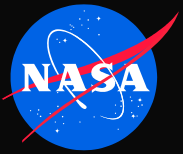
DM	Data Management Data Manager
DMP	Data Management Plan
DRD	Data Requirements Description
EAA	Enterprise Associate Administrator
ECO	Engineering Cost Office
ECR	Engineering Change Request
ED	Engineering Directorate
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EO	Engineering Order
FCA	Functional Configuration Audit
FMC&A	Functional Mission Concepts & Architecture
FMEA	Failure Modes and Effects Analysis
FOR	Flight Operations Review
FTA	Fault Tree Analysis
FTE	Full Time Equivalent
FRR	Flight Readiness Review
GOR	Ground Operations Review
GPMC	Governing Program Management Council
GSE	Ground Support Equipment
HDBK	Handbook



Acronyms

Systems Management Office

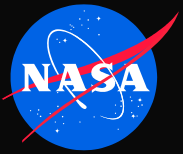
H/W	Hardware
IA	Independent Assessment
IAR	Independent Annual Review
ICD	Interface Control Document/Drawing
IDD	Interface Definition Document
INCOSE	International Council on Systems Engineering
IRD	Interface Requirements Document
IRN	Interface Release Notice
IRR	Integration Readiness Review
ISO	International Standards Organization
ISS	International Space Station
IV&V	Independent Verification & Validation
IWG	Interface Working Group
JIS	Joint Integrated Simulation
LCC	Life Cycle Cost
LSE	Lead Systems Engineer
LSSE	Lead Subsystems Engineer
M	Million
MDM	Multiplexer / DeMultiplexer
MIL	Military
MIUL	Material Identification & Usage List
MMOD	Meteoroids and Orbital Debris



Acronyms

Systems Management Office

MPD	Marshall Policy Directive
MPG	Marshall Procedures & Guidelines
MSFC	Marshall Space Flight Center
MUA	Material Usage Agreement
MWI	Marshall Work Instruction
NAR	Non Advocate Review
NASA	National Aeronautics and Space Administration
NHB	NASA Handbook
NIAT	NASA Integration Action Team
NPD	NASA Policy Directive
NPG	NASA Procedures & Guidelines
NRA	NASA Research Announcement
OMB	Office of Management & Budget
OPR	Office of Primary Responsibility
PCA	Program Commitment Agreement
	Physical Configuration Audit
PCN	Program Control Number
PDR	Preliminary Design Review
PED	Payload Experiment Developer
PIRN	Preliminary Interface Revision Notice
PM	Program/Project Manager
PMC	Program Management Council



Acronyms

Systems Management Office

POC	Point of Contact
POP	Program Operating Plan
PRA	Probabilistic Risk Assessment
PRR	Project Requirements Review
PSR	Pre-Ship Review
PSRB	Payload Safety Review Board
PSRRB	Payload Safety Readiness Review Board
QA	Quality Assurance
RFP	Request for Proposal
RID	Review Item Discrepancy
R&M	Reliability & Maintainability
SAR	System Acceptance Review
SE	Systems Engineering
SEMP	Systems Engineering Management Plan
SEO	Systems Engineering Office
SIM	Simulation
S&MA	Safety & Mission Assurance
SMO	Systems Management Office
SOW	Statement of Work
SP	Special Publication
SPA	Strategic Planning Agreement
SRD	System Requirements Document



Acronyms

SRR	System Requirements Review
STD	Standard
STS	Space Transportation System
S/W	Software
TIM	Technical Interchange Meeting
TPM	Technical Performance Measurement
TRR	Test Readiness Review
VRSD	Verification Requirements & Specification Document
WBS	Work Breakdown Structure



References

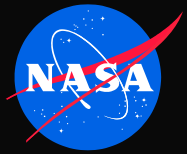


MPD's, MPG's, and MWI's

Systems Management Office

The following list of MPD's, MPG's, and MWI's can be found at
<https://msfcmr03.msfc.nasa.gov/directives/directives.htm>

MPD 1280.1	Marshall Management Manual
MPD 8720.1	MSFC Maintainability and Maintenance Planning for Space Systems
MPG 1230.1	Center Resources Management Process
MPG 1440.2	MSFC Records Management Program
MPG 1700.2	System Safety Program
MPG 2190.1	MSFC Export Control Program
MPG 6410.1	Handling, Storage, Packaging, Preservation, and Delivery
MPG 7120.1	Program/Project Planning
MPG 8730.1	Inspection and Testing
MWI 1700.1	Payload Safety Readiness Review Board
MWI 1700.2	System Safety Program
MWI 5116.1	Evaluation of Contractor Performance Under Contracts with Award Fee Provisions
MWI 7120.1	Project Quality Plan
MWI 7120.2	Data Requirements Identification/Definition
MWI 7120.4	Documentation Preparation, Programs/Projects
MWI 7120.5	Data Management Plans, Programs/Projects
MWI 7120.6	Risk Management
MWI 8050.1	Verification of Hardware, Software, and Ground Support Equipment for MSFC Projects



NPD's and NPG's

Systems Management Office

The following list of NPD's and NPG's can be found at
https://nodis3.gsfc.nasa.gov/library/main_lib.html

NPD 7120.4	Program/Project Management
NPD 2820.1	Managing Information Technology Requirements
NPD 7500.1	Program and Project Logistics Policy
NPD 8700.1	NASA Policy for Safety and Mission Success
NPG 5800.1	Grant and Cooperative Agreement Handbook
NPG 7120.5	Program and Project Management Processes and Requirements
NPG 9501.2	NASA Contractor Financial Management Reports

Handbooks



Systems Management Office

The following list of MSFC Handbooks are available at the following website:

<https://msfcmr03.msfc.nasa.gov/standards/build.htm?group=MSFC-HDBK>

MSFC-HDBK-1912 2nd Edition Systems Engineering Handbook

Vol. 1: Overview and Processes

Vol. 2: Tools, Techniques, and Lessons Learned

MSFC-HDBK-2221 Verification Handbook

Vol. 1: Verification Process DCN 001 Change 1

Vol. 2: Verification Documentation Examples

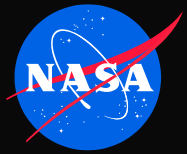
MSFC-HDBK-3173 Multi-Program/Project Common-Use Document, Project Management and Systems Engineering Handbook

The following MIL Handbooks are available at:

<http://web2.deskbook.osd.mil/default.asp>

MIL-HDBK-502 Acquisition Logistics

MIL-HDBK-881 Work Breakdown Structure



Handbooks, Etc.

The NASA Handbooks listed are available through the following website:

<http://www.sti.nasa.gov>

NASA SP-6105 NASA Systems Engineering Handbook

KSC-K-STSM-14.1 Launch Site Accommodations Handbook for STS Payloads

NASA RP-1358 Systems Engineering Toolbox for Design-Oriented Engineers

The following is available at: <http://sspweb.jsc.nasa.gov/webdata/pdcweb/subdocs.htm>

JSC-NSTS-5300.4 Safety, Reliability, Maintainability and Quality Provisions for the
Space Shuttle program

The following MIL Standard is available through: <http://standards.nasa.gov/NPTS/login.taf>

MIL-STD-961 Department of Defense Standard Practice Defense
Specifications

The NASA WBS handbook is available at: http://appl.nasa.gov/tools/tools_wbs.htm

Requirements References



Systems Management Office

- **MWI 7120.4** - Documentation Preparation, Programs/Projects
- **MIL-STD-961** - Department of Defense Standard Practice Defense Specifications
- **MSFC-HDBK-1912** - MSFC Systems Engineering Handbook
- **SP-6105** - NASA Systems Engineering Handbook

Verification References



Systems Management Office

- **MWI 8050.1** - Verification of Hardware, Software, and Ground Support Equipment
- **MSFC-HDBK-2221** - Verification Handbook Vol 1 & 2
- **MSFC-HDBK-1912** - MSFC Systems Engineering Handbook
- **SP-6105** - NASA Systems Engineering Handbook
- **Data Requirements Description (DRD) - MWI 7120.2**
(http://masterlist.msfc.nasa.gov/iso9000/drd/drd_masterlist.taf)
 - STD/VR-REQ - Verification Requirements
 - STD/VR-VP - Verification Planning
 - STD/VR-VSC - Verification Success Criteria
 - STD/VR-VR - Verification Reports
 - STD/VR-VC - Verification Compliance
- **EL22-001-BPVER** - System Verification Process
(This document is available from Pat McDuffee (544-9163) or Neil Rainwater (544-8918) in the Systems Management Office)

Systems Analysis & Trade Study

References



Systems Management Office

- NASA Reference Publication 1358, Systems Engineering “Toolbox” for Design-oriented Engineers.
- Systems Engineering Process Activities, a “How-to” Guide; International Council on Systems Engineering (INCOSE).
- ANSI/AIAA G-020-1992, Estimating and Budgeting Weight and Power Contingencies for Spacecraft Systems.
- An Identification of Pragmatic Principles, INCOSE Report, January 1993, J.C. DeFoe (ed.).
- Buede, Dennis M. The Engineering Design of Systems, Wiley Interscience, 2000.
- Goodwin, Paul and Wright, George, Decision Analysis for Management Judgment, John Wiley & Sons, 1998

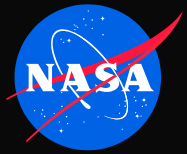
Integration and Operations References



Systems Management Office

- MPG 8730.1, Inspection and Testing
- MIL-HDBK-502, Acquisition Logistics
- MPG 6410.1, Handling, Storage, Packaging, Preservation, and Delivery
- K-STSM-14.1, Launch Site Accommodations Handbook for Payloads
- NPD 7500.1, Program/Project Logistics Policy

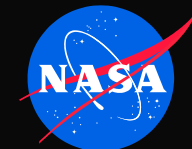
Safety and Mission Assurance References



Systems Management Office

- NPD 8700.1, NASA Policy for Safety and Mission Success
- MPD 1280.1, Marshall Management Manual
- MWI 1700.1, Payload Safety Readiness Review Board
- MPG 1700.2, System Safety Program
- MWI 7120.1, Project Quality Plan
- MPD 8720.1, MSFC Maintainability and Maintenance Planning for Space Systems
- MWI 7120.6, Risk Management
- NSTS 5300.4 (D-2) Safety, Reliability and Quality Assurance Requirements for the Space Shuttle Program

Project Activities/Reviews References



Systems Management Office

- MSFC Data Requirements Management System
(Listing of DRs, POCs, Milestone Review Products)
<http://masterlist.msfc.nasa.gov/drm/>
- MSFC Multi-Program/Project Common use Documentation
(Handbooks, Specs, Plans...)
http://inside.msfc.nasa.gov/MIDL/project_docs.html
- NASA Systems Engineering Handbook, SP6105
- (NPG 7120.5 Cross Reference to MSFC ISO Procedures, MSFC's 7120.1 Integrated flow, MPG 7120.1 "MSFC's ISO Procedure for NPG 7120.5")
http://SMO.msfc.nasa.gov/SMO/Custommer/Director/MSFC7120_5Matrix.xls



Miscellaneous

Systems engineering Process Activities, a “How-To” Guide;
International Council on Systems Engineering (INCOSE)

ANSI/AIAA G-020-1992, Estimating and Budgeting Weight and
Power Contingencies for Spacecraft Systems

An Identification of Pragmatic Principles, INCOSE Report, January
1993, J. C. DeFoe (editor)

NPG 7120.5 Cross Reference to MSFC ISO Procedures

(SMO Website):

http://SMO.msfc.nasa.gov/SMO/Customer/Director/MSFC7120_5Matrix.xls